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Soil Properties in Natural Forest Destruction and Conversion to Agricultural Land, in *Gunung Leuser* National Park, North Sumatera Province

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Abstract

Destruction of the Gunung Leuser National Park area of North Sumatera Province through land clearing and land cover change from natural forest to agricultural land. Less attention to land use and ecosystem carrying capacity of the soil can cause soil degradation and destruction of flora, fauna, and wildlife habitat destruction. Environmental damage will result in a national park wild life will come out of the conservation area and would damage the agricultural community. Soil sampling conducted in purposive sampling in natural forest and agricultural areas. Observation suggest that damage to the natural forest vegetation has caused the soil is not protected so that erosion has occurred. Destruction of natural forest into agricultural are as has caused damage to soil physical properties, soil chemical properties, and biological soil properties significantly. Forms of soil degradation caused by the destruction of natural forests, which is an increase in soil density (density Limbak) by 103%, a decrease of 93% organic C and soil nitrogen decreased by 81%. The main factors causing soil degradation is the reduction of organic matter and soil erosion due to loss of natural forest vegetation. Criteria for soil degradation in Governance Regulation Number 150/2000 can be used to determine the extent of soil degradation in natural forest ecosystems.

Keywords: Gunung Leuser National Park, natural forest, agricultural land, land damage, soil properties

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Introduction

Tropical rain forest contains very great biodiversity. According to Whitmore (1975) within the Southeast Asia tropical rain forest, there are 25–30 thousand species. Sumatera island contains more than 10,000 species of higher plants which mostly grow in lowland forest. In terms of fauna, Sumatera island is the richest in Indonesia because of possession of 210 species of mammals (9 endemic species), 580 species of bird (19 endemic spesies), 194 species of reptile, 62 species of amphibian, and 272 species of freshwater fishes (30 endemic species) (Mackinon 2000; Bappenas 2003). Besides that, tropical rain forest posseses activities and metabolism ability which are much larger as compared to those forests of subtropics, temperate region, and boreal region due to exposure to solar radiation for the whole year. However, the high temperature and rainfall in tropical region causes even greater rate of weathering, decomposition, surface run off, nutrient leaching, and erosion (Wahyudi 2011). *Gunung Leuser* National Park is one of the pockets or locations of conservation (Bappenas 2003).

Destruction of *Gunung Leuser* National Park area, Subdistrict of *Bohorok*, District of *Langkat*, Province of North Sumatera was conducted through illegal logging, forest land encroachment, and altering of land cover from natural forest to agricultural land and plantation. These activities are actually prohibited because this location belongs to territories which are free from any forms of intensive land utilization. Destruction activities of the conservation area are in the form of road construction, tree felling, land clearing, soil tillage, and planting of agricultural crops. Observation result showed that area size of natural forest being destroyed was around 5,250 ha. According to Takandjandji and Sawitri (2011) natural forest destruction in national park area will disturb the habitat of wildlife.

Soil utilization which does not pay attention to the aspects of carrying capacity, soil, and ecosystem will damage the soil and the existing life (flora, fauna, and their habitat). Environmental damage of national park will cause expulsion of wild animals from conservation area, and will damage the farm land of local people (Heriyanto & Mukhtar 2011). Environmental destruction is action which cause direct and indirect change toward physical and biological properties of the environment, and result in environment which is not able anymore to support sustainable development (Oldeman 1992; Government Regulation (PP) Number 150/2000).

Soil destruction will result in deterioration of soil quality. There is a general agreement that soil quality comprise 3 main aspects, namely sustainable productivity of plants, environmental quality (soil, air, and water), and organism health. Therefore, assessment on a land management system, especially on land function, should be related with one of those issues.

Change in land use from forest to agricultural land will result in damage to soil properties (Barrow 1991; Wasis

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2006). Increase in soil nutrient loss through erosion and leaching will be more progressive due to lost or decrease of vegetation cover. Harvesting activities usually cause lost of nutrient elements N, P, K, calsium (Ca), magnesium (Mg); and micro elements from the soil (Binkley 1987; Hardjowigeno 2005). According to PP Number 150/2000, soil damage is the change in soil basic properties which exceed the standard criteria of damage.

The objective of this research was analyzing the impact of natural forest destruction and conversion to agricultural land on soil damage which was related with soil physical, biological, and chemical properties in *Gunung Leuser* National Park.

Methods

This research was conducted in *Gunung Leuser* National Park area, Subdistrict of Bahorok, District of Langkat, Province of North Sumatera. Equipments used in this research were categorized into equipments for field data collection and those for nutrient analysis in laboratory. Equipments for field data collection were those for collecting undisturbed soil sample (in the form of ring sampler) and composite sample (in the form of hoe, machete, measuring tape, and plastic pocket).

The main materials being studied were undisturbed soil samples and composite soil samples originated from *Gunung Leuser* National Park area which represented natural forest soil and agricultural land soil (encroached natural forest).

Soil sample collection Soil sample collection was conducted through purposive sampling in natural forest and in agricultural land. This research was conducted in three plots in natural forest and agricultural land with size of 20 × 20 m (0.04 ha) for each plot. Within the plot, there were three sub plots measuring 1 × 1 m each, which were placed randomly for collection of soil samples. The soil samples were afterwards be composited.

Soil sample collection for soil physical, chemical, and biological properties were performed uniformly on soil surface, down the depth of 20 cm. Soil sample collection was conducted in composite manner as much as 1 kg. Sample collection for soil physical properties were conducted on soil surface, down to the depth of 20 cm. Soil samples were collected as undisturbed soil sample by using ring sampler with diameter of 7 cm and height of 5 cm.

Soil analysis Collected soil samples from the field were afterwards analyzed in Soil Laboratory, Department of Soil and Land Resources, Faculty of Agriculture, IPB. Soil analysis for physical properties, comprised bulk density, porosity, available water and permeability; whereas those for chemical properties comprised soil pH, organic C, nitrogen (N), and calcium (Ca). For soil biological properties, the analysis comprised soil microorganism, phosphorus dissolving bacteria, soil fungi, and soil respiration. The locations of soil sample collection for natural forest and agricultural land were adjacent to each other, so that it could be assumed that there were no significant differences in terms of soil type, topography, climate, and other factors.

Data analysis Data from soil laboratory analysis were afterwards analyzed statistically by using test of mean differences at confidence interval of 95%. Variables for soil physical properties were bulk density, porosity, available water and permeability; whereas those of soil chemical properties were soil pH, organic C, N, and Ca; and those of soil biological properties were soil micro organisms, phosphorus dissolving bacteria, soil fungi, and soil respiration. For learning the effect of destruction of *Gunung Leuser* National Park, analysis was conducted on standard value of damage on the basis of standard criteria of soil damage for biomass (PP Number 150/2000).

Results and Discussion

Soil physical properties The analyzed soil physical properties were bulk density, porosity, water content, and soil permeability. Analysis results on soil physical properties could be seen in Table 1. Results of statistical test for mean differences related with impact of natural forest destruction and conversion to agricultural land, showed that there had been very significant change in bulk density and available water, and there had been significant differences for porosity and permeability.

Activities of natural forest destruction and conversion to agricultural land has increased bulk density by 0.69 g cm^{-3} (103%), namely from 0.67 g cm^{-3} in the forest to 1.36 g cm^{-3} in agricultural land. Increase in soil density was due to land

Table 1 Condition of soil physical properties due to conversion of natural forest to agricultural land in *Gunung Leuser* National Park

Physical properties	Natural forest	Agricultural land	Change
Bulk density (g cm^{-3})	0.67 ± 0.17**	1.36 ± 0.14	+ 0.69 (103%)
Porosity (%)	74.14 ± 6.51*	48.59 ± 5.39	-25.55 (34%)
Available water (%)	16.53 ± 1.02**	10.79 ± 1.69	-5.74 (35%)
Permeability (cm $hour^{-3}$)	11.72 ± 3.35*	2.24 ± 1.34	-9.48 (81%)

** : highly significant at 99% confidence interval
* : significant at 95% confidence interval

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clearing using heavy machinery, such as tractor, which cause damage on soil structure. Besides that, the impact of soil compaction will damage soil pores. Research results proved that in this location there was also damage on soil pores, namely decrease of soil porosity by 25.55% (34%). More detailed information could be seen in Table 1 and Figure 1.

Other impact due to destruction and conversion of natural forest to agricultural land was soil deterioration related with water conservation. This was indicated by decrease in the ability of soil to transmit (drain off) water, as proven by decrease of permeability by 9.48 cm hour^{-1} (81%), namely from 11.72 cm hour^{-1} for natural forest to 2.24 cm hour^{-1} for agricultural land. The result of this is that rainfall which fall down on the ground will become surface run off if permeability is exceeded by rainfall.

Soil damage due to forest logging and the use of heavy machinery was in the form of decrease in available water by 5.74% (35%). This was because clay fraction and organic matter content in soil surface decreased due to the scraping of topsoil by heavy machine and erosion.

This research results showed that natural forest logging and land clearing with heavy machinery have caused damage on soil physical properties. The most important soil physical properties in relation with forest, were water content, permeability, porosity, drainage, and soil infiltration, where if the soil were not covered by tree crown, there will be destruction on soil physical properties. On soils which were not covered by tree crown, the raindrops will fall directly on soil surface, so the structure of forest soil become damaged or destroyed, or there will be soil compaction. Damage on soil structure will reduce soil porosity, permeability and soil infiltration so that all of these would cause surface run off and soil erosion. On the whole, soil damage in the form of poor soil physical properties will impoverish the hydrological function of *Gunung Leuser* National Park. This research results were in agreement with that of Hendrayanto *et al.* (2001) which explained that surface run off/flood could be caused by decrease in soil infiltration capacity and impoverishment of land cover vegetation. The same phenomenon was also reported by Aminudin (2012) who found that logging of natural forest and conversion of it to planting strip has caused decrease in permeability by 2.92 cm hour^{-1}, decrease in porosity by 2.93%, and decrease in available water by 3.22%, and increase in bulk density by 0.08 g cm^{-3}.

The effect of vegetation on soil erosion varies depending on plant species, rooting system, plant height, crown, growth level, and season. The effect of season was actually related with forest management and or plants (Rahim 2006). Existence of appropriate ground cover, such as thick grasses and dense forest could eliminate the effect of topography toward erosion. Dense ground cover will not only retard surface run off, but also retard the transportation of soil particles. Species of plants being cultivated would play an important role in erosion prevention (Arsyad 2006).

Plant roots play some role as enhancer of soil aggregate. Roots also function to "grip" soil mass, so that it affect the value of soil shear strength. Therefore, soil which has plant roots, possesses high permeability. Plants which have significantly different characters will behave differently in interacting with soil. Plants which have dense foliage will be decomposed more rapidly to fertilize the soil, so that this phenomenon will reduce the soil's susceptibility toward erosion (Rahim 2006). In general, erosion in natural forest which is still dense, is the lowest and often referred to as geologic erosion (Arsyad 2006).

Soil chemical properties The analyzed soil chemical properties were pH, Cation Exchange Capacity (CEC), organic C, total-N, phosphorus (P), and Ca. Results of soil chemical analysis are presented in Table 2. On the basis of statistical analysis results using test for mean differences, it was known that in terms of soil cation exchange capacity and organic C, the types of land use, were significantly different. In terms of N, P, and Ca the 2 types of land uses had highly significant difference. For soil pH, the land uses did not exhibit significant difference.

Conversion of natural forest to agricultural land has reduced soil ability to store nutrients. This was proven by the occurrence of CEC decrease. Soil CEC decreased by 17.95 me 100 g^{-1}(69%), namely from 26.10 me 100 g^{-1} in natural forest to 8.15 me 100 g^{-1} in agricultural land. Forest and soil destruction caused impoverishment of soil chemical properties, namely organic C, N, P, and Ca. Soil organic C decreased by 7.14% (93%); while those of nitrogen 0.26% (81%), phosphorus 4.5 ppm (55%), and calcium 1.28 me 100 g^{-1} (81%). More detailed information could be seen in Table 2 and Figure 2.

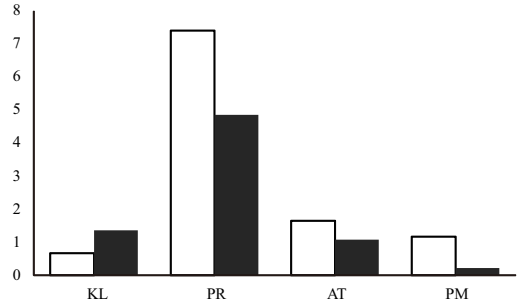

Figure 1 Change of soil physical properties due to conversion of natural forest to agricultural land. KL (bulk density, g cm^{-3}), PR (porosity, %), AT (available water, %), PM (permeability, cm hour^{-1}), forest (□), agriculture (■).

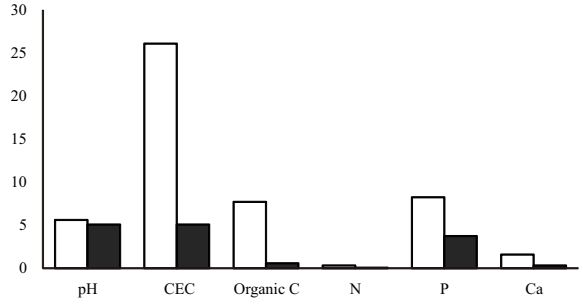

Figure 2 Change in soil chemical properties due to conversion of natural forest to agricultural land. pH (soil acidity), CEC (Cation Exchange Capacity, me 100 g^{-1}), organic C (%), N (nitrogen, %), P (phosphorus, ppm), Ca (calcium, me 100 g^{-1}), forest (□), agriculture (■).

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Table 2 Condition of soil chemical properties due to conversion of natural forest to agricultural land in *Gunung Leuser* National Park

Chemical properties	Natural forest	Agricultural land	Change
pH	5.60 ± 0.10 ^{tn}	5.07 ± 0.23	-0.53 (9%)
CEC (me 100 g^{-1})	26.10 ± 6.07 *	8.15 ± 0.59	-17.95 (69%)
Organic C (%)	7.71 ± 0.33 *	0.57 ± 0.40	- 7.14 (93%)
Nitrogen (N) (%)	0.32 ± 0.04 **	0.06 ± 0.03	- 0.26 (81%)
Phosphorus (P) (ppm)	8.23 ± 0.32 **	3.73 ± 0.31	- 4.5 (55%)
Calcium (me 100 g^{-1})	1.59 ± 0.65 **	0.31 ± 0.15	- 1.28 (81%)

** : highly significant at 99% confidence interval
* : significant at 95% confidence interval

Natural forest destruction resulted in loss of natural forest biomass, which will in turn create ecosystem improverishment. Activity of natural forest destruction which caused impoverishment of soil chemical properties was tree felling (logging).

Tree felling in natural forest affects the nutrient cycle of the ecosystem. Loss of natural forest caused decrease or loss of supply of twigs, leaves, litter and organic matter to the soil. Such reduction in supply of organic matter will of course cause reduction of soil nutrient contents, such as N, P, Ca, Mg, and K.

This soil organic matter will undergo decomposition to simpler compounds. Besides that, the organic matter will also undergo mineralization. Organic matter decomposition will produce organic matter which is relatively resistant toward further decomposition (humic compounds) and part of the product will be released as nutrients which can be utilized again by plants. Therefore, end result of organic matter decomposition process will affect, directly or indirectly toward soil chemical properties. Because of such importance of organic matter function, the decrease of soil organic matter content should be watched closely.

This research showed that activity of natural forest destruction had caused significant decrease in soil fertility. This is in agreement with researches which have been conducted by others, which showed that logging of natural forest poses a risk for land productivity decrease. Logging of natural forest has caused impoverishment of nutrient elements of soil N, P, K, Ca, and Mg (Wahyudi 2011; Aminudin 2012). Also, Indrawan (2003) showed that logging in natural forest in first rotation will increase logging interval in the second rotation.

Harvesting of natural forest stand will cause loss of biomass in the form of tree stems (log). In natural forest, tree stem part (log) constitutes the largest biomass as compared to other plant organs, such as branches, twigs, and leaves. Therefore, harvesting of natural forest becomes the main indirect cause of soil nutrient decrease (Binkley 1987; Evan 2000; Wasis 2006; Aminudin 2012).

Logging of natural forest has broken the nutrient cycle in forest ecosystem. Research results of Aminudin (2012) showed that logging in natural forest at planting strip (clean strip) in TPTI silvicultural system (Indonesian selective cutting and planting) has caused decrease in organic C by 0.76%, soil N by 0.03%, soil P by 5.83 ppm, soil K by 0.043 me 100 g^{-1}, soil Ca by 0.44 me 100 g^{-1}, and soil Mg by 0.20 me 100 g^{-1}.

One form of soil damage is loss or decrease of soil organic matter content. Decrease in soil organic matter content occurs more rapidly in upper layer (*top soil*) as compared to that in lower layer of the soil (*sub soil*). Tree felling will result in the breaking of nutrient cycle. Imbalance between organic matter input and loss which occur through decomposition will result in decrease of soil organic matter in the soil. Decrease in soil organic matter will result in poor long term sustainability, due to important role of organic matter in plant growth, through its influence on soil physical, chemical and biological properties. Those factors will in turn affect soil structure, infiltration rate, water holding capacity, plant nutrient availability and mineralization rate. In cultivated soil of agricultural land, top soil layer (0–30 cm) lose 20–60% of carbon which occur in natural forest vegetation.

Damage in soil chemical properties was due to damage in nutrient cycle of natural forest because of logging. Research results of Indrawan (2003) showed that the structure and composition of primary forest will determine the intensity level of forest harvesting. The higher the density of mature trees and commercial tress being logged, the greater will be the impact of the damage. Damage in logged over area will affect the:

1 Availability of core trees and their regeneration
2 Nutrient availability of forest soil
3 Other environmental components, such as temperature, humidity, and others.

Improvement of chemical properties could be conducted by application of compost fertilizer or green manure which is originated from *Gunung Leuser* National Park area. It is heavily emphasized that application of inorganic fertilizer (fertilizer made in factories) is not recommended because this will cause pollution. Planting stocks being used for reforestation should be in the form of native species (endemic) (Wasis & Noviani 2010; Wasis & Fathia 2011).

Soil biological properties The analyzed biological properties were total microorganism, total fungi, P dissolving

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bacteria, and soil respiration. Analysis results of biological properties could be seen Table 3. Analysis results of test for mean differences for variables of total microorganism and respiration showed highly significant difference, whereas those for total fungi and P dissolving bacteria, showed significant difference.

Natural forest destruction has decreased total soil microorganism, total soil fungi, P dissolving bacteria and soil respiration. Those decrease can be detailed as follows: for total soil microorganism 9.00×10^6 cfu (59%), for soil fungi 4.16×10^4 cfu (86%), for P dissolving bacteria 4.33×10^3 cfu (81 %) and for soil respiration 3.35 mg C-CO_2 kg^{-1} of soil/day (45%). This research results proved that natural forest destruction also destroyed soil biological properties. For clearer information, Table 3 and Figure 3 can be examined.

Destruction of natural forest in *Gunung Leuser* National Park has decreased soil microorganism. Natural forest destruction should not be conducted because it turned out that in the soil there was also storage of genetic resources and high diversity of microorganisms. Presence of micro-organism also function to maintain soil fertility. According to Rao (1986) soil microorganism is highly needed for maintaining soil fertility and play important role for nutrient cycle. Improvement of forest soil could be conducted by inoculation of VA-mikoriza and inoculation of *Rhizobium* to increase plant growth (Rumondang & Setiadi 2011; Tuheteru & Husna 2011).

Recovery of damaged soil in *Gunung Leuser* National Park could be conducted by application of compost fertilizer or animal manure, inoculation of microorganism (mycorrhiza) and planting of endemic species of vegetation (Arif *et al.* 2009). According to Nguyen and Klinnert (2001) application of organic fertilizer is highly recommended for maintaining plant productivity and soil fertility. Application of organic matter in soil constitutes the potential source of elements N, P, and S for plant growth. Microbiological decomposition of organic matter is an important step for dismantling nutrient bonding, so that the nutrient could be in the form available for plants (Kumada 1987). Application of mycorrhiza inoculation is highly needed for increasing plant growth and nutrient conservation (Ulfa *et al.* 2009).

Soil damage According to Number 150/2000 concerning control of soil damage for biomass production, the standard criteria of damage which was exceeded were bulk density, decrease of soil organic matter, and decrease of soil N content. On the basis of measurement results, there had been soil erosion in road bodies. The occurring erosion was in the form of gully erosion (gully type of erosion). Measurement results on gully erosion showed that there were 2 forms of gully erosion. The first gully erosion had width of 30 cm, depth of 200 cm, and length of 7 m; whereas the second erosion had width of 20 cm, depth of 30 cm, and length of 3 m. This phenomenon showed that natural forest destruction in *Gunung Leuser* National Park had caused the occurrence of surface run off. The result of such surface run off was gully erosion.

On the basis of field observation results and laboratory analysis, damage in *Gunung Leuser* National Park had fulfilled 2 standard criteria in PP Number 150/2000. The standard criteria which had been fulfilled were standard criteria of soil damage in dry land due to water erosion and standard criteria of soil damage in dry land. By observing the facts and the fulfillment of standard criteria of damage, then it could be concluded that in this location, there had been soil damage.

On the basis of this research, it can be stated that there had been soil damage due to tree felling in natural forest. This is in agreement with Oldeman (1992) who explained that soil damage is a process where there has been decrease in soil capacity, either at present or in the future, for creating products or services. The first category of soil degradation is related with movement of soil material, whereas the second category is related with in situ degragation of soil in the form of chemical (decrease in soil organic matter and nutrient loss) and/or physical degradation (Barrow 1991; Oldeman 1992). The main functions of soil according to Hardjowigeno (2005) comprises of :

1 Serving as resource for storing and cycling of nutrients in soil biosphere which is needed for the growth of plants and forages.
2 Serving as matrices for root to anchor and grow, and as storage place and regulator of water/water flow/solution.
3 Filtering, preventing, and decreasing poisonous material content in soil organic and inorganic materials.

Impact of ecosystem damage in *Gunung Leuser* National Park was also in the form of soil damage. In the last several years, natural forest destruction in the national park has

Table 3 Condition of soil biological properties due to conversion of natural forest to agricultural land in *Gunung Leuser* National Park

Soil biological properties	Natural forest	Agricultural land	Change
Total microorganism ($\times 10^6$ cfu)	15.17 ± 1.53 **	6.17 ± 2.75	- 9.00 (59%)
Total fungi ($\times 10^4$ cfu)	4.83 ± 1.04 *	0.67 ± 0.58	- 4.16 (86%)
P dissolving bacteria ($\times 10^3$ spk)	5.33 ± 0.76 *	1.00 ± 1.00	- 4.33 (81%)
Respiration (mgC-CO_2 kg soil day)	7.46 ± 0.26 **	4.11 ± 0.75	3.35 (45%)

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* : significant at 95% confidence interval

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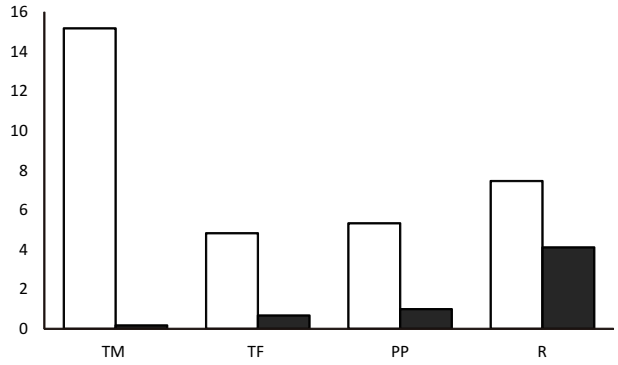

Figure 3 Change in soil biological properties due conversion of natural forest to agricultural land. TM (total microorganism, × 10^6cfu), TF (total fungi, × 10^4cfu), PP (phosphate dissolving bacteria, ×10^3 cfu), R (soil respiration, mgC-CO_2 kg^{-1} of soil day^{-1}), forest (□), agricultural (■).

entered the very dangerous phase for the safety of flora, fauna, and environment.

Soil as one of the environmental components is easy to be degraded if the management does not pay attention to soil characteristics. Therefore, soil utilization should consider soil characteristics for a certain management objective. In general, attention toward soil quality is related with intensity of soil cultivation. Soil quality becomes the main priority in an ecosystem assessment. As well as becomes an inseparable part and even as the key indicator for sustainability of soil and ecosystem management concept.

This research results showed that soil in tropical forest is very sensitive toward change in its management. This was shown by highly significant impoverishment in soil chemical, physical, and biological properties of the soil. Therefore, change in the structure of land cover will decrease the soil quality. On the other hand, existence of natural forest cover will act as nutrient conservation. Litter in forest floor which is rapidly decomposed will be absorbed again by vegetation to run metabolism, and this process goes on and on forming a closed nutrient cycle. Tree felling in natural forest will result in loss of most of the natural vegetation. In the development of agricultural land, activities which were conducted were felling trees of natural forest, soil cultivation/tillage (mechanically or by burning), and planting of agricultural crops. These activities will eliminate the closed nutrient cycle (Wasis 2006). For safe guarding and protecting *Gunung Leuser* National Park, several things need to be conducted, namely providing access on data dan information, law enforcement, and adaptive management (institutional aspects) (Bawole *et al*. 2011; Ohorella *et al*. 2011). Besides that, for supervising change in land cover there can be used spatial analysis using *Landsat* imagery so that soil and forest damage could be detected rapidly and accurately since the beginning of the problem (Mulyanto & Jaya 2004).

Conclusion

Destruction of natural forest and conversion into agricultural land had significant impact on soil physical, chemical, and biological properties of soil. In general, variables of soil physical, chemical, and biological properties in agricultural land were poorer than those in natural forest. On the basis of standard criteria of damage, it can be concluded that in the agricultural land, there had been soil damage. Criteria of soil damage in PP Number 150/2000 could be used for determining the level of soil damage in natural forest ecosystem.

Recommendation

In the area of *Gunung Leuser* National Park which has suffered from soil and forest damage, there should be urgent act of reforestation by adding organic matter (compost, litter), inoculation of beneficial soil microorganism, addition of topsoil material, and planting of endemic species.

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