Effects of biopore infiltration holes and cross drain on soil properties on skidding roads and natural production forest

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Abstract. Logging activities in natural production forests tend to have negative impacts on soil quality. This study aims to examine the effect of biopore infiltration holes and cross drains on the chemical and physical properties of the soil both on skid trails and in natural forests. The study was conducted at a natural production forest in West Kalimantan. The results showed that there was no significant change in the chemical properties of the soil in both the skid trails and in natural forests. The increase in organic C from 1.16% to 2.04% (~3%) on the skid trails before and after one year. In general, there was a change in the physical properties of the soil on the skid trails. The natural forest, the bulk density is lower than that on the skid trails and tends to increase with soil depth. Porosity in the center of the skid trails decreases by 24% compared to that in the natural forests at a depth of 0-10 cm. The phenomenon of degradation is also apparent in the parameters of available water, soil permeability, and drainage pores in the middle of the skid trails.

1. Introduction

Forest productivity is a demand that must be fulfilled in the natural production forest management in Indonesia. Productivity itself is decided by the quality of sites to plant and the developed silvicultural techniques. Management of natural resources (forests) will be sustainable if it maintains high productivity per unit area continuously and improves soil quality [1]. Several silvicultural systems have been applied to maintain forest preservation for both productivity and ecosystem sustainability. Those were the Indonesian Selective Cutting System (TPI), Indonesian Selective Cutting and Planting (TPTI), Clear Felling with Artificial Regeneration (THPA), Selective Cutting and Strip Planting (TPTJ) and Indonesian Intensive Selective Cutting and Planting (TPTII) according to the local ecosystem conditions. The application of each of these silvicultural systems has different logical consequences for the biophysical nature of the forest being managed and its techniques of rehabilitation.

Timber harvesting or logging and skidding activities in silvicultural systems in Indonesia have caused many damages to residual stands, changes in stand structure, changes in properties of soil, erosion and micro-climate changes. The nature of the soil that is generally damaged is the physical nature of the soil. Various heavy equipment in skidding activities such as tractors has caused soil compaction [2]. Soil compaction that occurs for a long time can harm soil properties and also plant growth.
Parameters of soil physical characteristics that are damaged due to natural forest logging include soil porosity [3, 4, 5], water content [6], bulk density and soil permeability. In addition to physical soil, soil chemical properties are also affected by logging activities. Clearing of forest areas and making skid trails cause a decrease in soil fertility caused by the loss of organic matter in the topsoil layer, soil erosion, deficient nutrient, and relatively significant loss of natural regeneration on skid trails [7]. Organic matter loss can have an impact on the population and activity of soil microorganisms [8]. [9] and [10] concluded that there was a decrease in soil quality in the application of Indonesian silviculture systems in natural forests in Kalimantan.

The main challenge in rehabilitating logged-over production forests, especially in natural production forests, is to create suitable growing conditions for the growth of tree species. The initial step needed to be taken to support these efforts is to determine the soil properties of the logged-over area, especially the skid trails. Understanding the nature of the soil becomes very important to determine the right silvicultural techniques. According to Pamoengkas [11], soil improvement combined with plant maintenance can increase plant growth and biomass.

To overcome the problem of soil density on skid trails is to use cross drains and biopore infiltration holes. The benefits of cross drains are to reduce surface runoff/erosion rates, control sedimentation, and direct surface runoff and rainwater percolation on skid trails so that they can restore skid trails to be planted [12 - 16]. While the use of biopore infiltration holes (BIHs) can increase the rate of water infiltration, increase soil fertility and facilitate plant roots to develop correctly, and stimulate the development of mycorrhizae and other microorganisms. BIHs are filled with organic materials such as litter and charcoal (bio-charcoal) to function as soil ameliorant to improve soil fertility and increase soil microorganism activity [17].

The objective of this study is to examine the effects of biopore infiltration hole (BIH) and cross drain (CD) installation on the chemical and physical properties of soil both on skid trails and in natural forests.

2. Materials and methods
2.1 Research site
The research site was located in the natural production forest of IUPHHK-HA PT. Suka Jaya Makmur, West Kalimantan. The research area is about 159 km from Ketapang city. Geographically it located between 110° 27' E - 111° 25 ' E and 01°00' S - 01°55' S with an altitude of 700 m above sea level.

2.2. Materials and tools
The soil was collected from the former skid trail. The GPS, compass, rope, boundary markers, PVC pipes, water sample bottles, paints and biopore drill boards, hoes, hammers, nails, paints, machetes, 50 m measure tape, cameras, funnels, analytical scales, drums, ovens, and porcelain cups were used for plot establishment.

2.3. Sampling plot establishment
Sampling plots were determined based on overlaid of three different maps, i.e., ITSP map, contour map and skid trail distribution map. The plots were established in the location with certain conditions, such as: located in the main skid trail with slopes ranging between 15 - 25% or 8.4° - 13.5°, indicated by widely separated contour line on the map, had been abandoned for a year and had poor tillers and thin litter.

There are three steps for establishing sampling plots. First, clean the former skid trails from dead stems, branches, twigs, and shrubs 160 m long and 4 m wide. Then make a trial plot of 20 m long 4 m wide, so the number of plots for each former skid trail is eight experimental plots. Lastly, place the construction of cross drain (CD) buildings at a distance of 20 m. The CD building is in the form of a mound sizing 4 m x 1 m perpendicular to the former skid trail.
2.4. Data collection

2.4.1. Soil sampling. Before taking soil samples for soil physical and chemical analyses, soil profiles were made. The soil profiles were made on three main skid trails that have been determined based on the overlay ITSP map, slope and skid trail map. The purpose of making a profile is to find out the thickness distribution of each soil horizon (O, A, B, C).

Soil samples for the analysis of soil physical properties were taken from the right, middle and left of the skid trail with depths of 0-10 cm, 10-20 cm and 20-30 cm in each plot with three replications. This is to determine the effect of tractor tires (left and right of the skid trail) and skidding logs (centon soil density). Soil sampling for soil physical properties used ring samples (5 cm in diameter and 6 cm long).

Soil samples for analysis of chemical properties were taken at five points (center and four corners) in each plot as deep as 5 cm, then mixed homogeneously/composite.

Soil samples for the analysis of soil physical and chemical properties were collected before and after planting *S. leprosula* and *S. parvifolia*. Soil samples were also taken in logged-over forests closed to the location of the research plot to determine changes in the physical and chemical properties of soil between the former skid trail and logged-over forest.

2.4.2. Experimental design and data analysis. The experimental design used was completely randomized design (CRD) factorial pattern with three replications. The first factor is biopore infiltration hole (B1: without biopore infiltration hole (BIH) and B2: with biopore infiltration hole (BIH)) and the second factor is cross drain (CD) technique (Cd1: without a cross drain (CD) and Cd2: with cross drain (CD) technique). The experiment was repeated at three skid trail locations. Obtained data were then analyzed with analyses of variance. If the results show significantly different at the level of P = 0.05, then further tests are performed with the Duncan Multiple Range Test (DMRT) [18].

3. Results and discussion

3.1. Physical properties of soil

3.1.1. Soil density. The general condition of skid trails and logged over forests before the installation of CD and BIH buildings is presented in Table 1. Generally, the condition of skid trails was poor natural regeneration of commercial tree species, less fertile, and overgrown with weeds and shrubs, even in some parts of the skid trails there were outcrops of rock or very dense subsoil. Commercial natural regeneration on the skid trails was not found even though the skid trails had been abandoned for one year. This was caused by the tiny amount of organic matter in the skid trails so that the skid trails became very poor in nutrients ready to be absorbed by plants. Natural regeneration was more common in logged forests than on skid trails, especially from *jabon* (*Anthocephalus cadamba*), *meranti* (*Shorea leprosula* and *S. parvifolia*), and *ulin* (*Eusyderoxylon zwageri*), because the soil was fertile, not dense and moist.

| Table 1. General conditions of logged-over forests and skidding road surfaces before the installation of CD buildings and BIH. |
|---|---|---|---|---|---|---|---|
| Skidding road (SR) | Slope (%) | Type of soil | Ground conditions | Types of cover plants | Land profile (cm) | Types of cover plants | Land profile (cm) |
| SR1 | 15-17 | Red yellow podzolic | Soil | *Imperata cylindrica*, liana, weeds, litter thick 1-2 cm. | O = 0 | Secondary forest | O = 0 |
| | | | | | A = 0 | A = 1-10 |
| | | | | | B = 0 | Jabon | B = 10-85 |
| | | | | | C = 85-105 | Meranti | C = 85-105 |
Results of the analysis of changes in soil density before and after treatment in logged-over forests and skid trails are presented in Table 2. Before BIH and CD installation showed that soil density on skid trails (right, left and center) at depths of 0-10 cm, 10-20 cm and 20-30 cm was higher than in logged forests. This caused by a result of log transportation activities through skid trails. The soil density on skid trails at 0-10 cm depth is 1.27-1.36 g/cm$^3$, at 10-20 cm depth is 1.23-1.33 g/cm$^3$ and at 20-30 cm depth is 1.28-1.33 g/cm$^3$, while the density the overall logged-over forest is still below the soil density on the skid trail (1.14-1.22 g/cm$^3$).

| Research sites | Depth (cm) | Before treatment (g cm$^{-3}$) | After treatment (g cm$^{-3}$) | Change (down / up) (g cm$^{-3}$) | (Percentage) down / up (%) |
|----------------|------------|---------------------------------|--------------------------------|----------------------------------|---------------------------|
| Logged         | 0-10       | 1.16                            | 0.94                           | Down 0.22                       | 18.97                     |
| Over areas     | 10-20      | 1.14                            | 1.22                           | Up 0.08                         | 7.02                      |
|                | 20-30      | 1.22                            | 1.23                           | Up 0.01                         | 0.89                      |
| Former right skidding road | 0-10 | 1.30                            | 0.99                           | Down 1.20                       | 92.31                     |
|                | 10-20      | 1.33                            | 1.08                           | Down 0.25                       | 18.80                     |
|                | 20-30      | 1.32                            | 1.01                           | Decrease 1.31                    | 23.08                     |
| Former middle skidding road | 0-10 | 1.27                            | 1.07                           | Down 0.20                       | 15.75                     |
|                | 10-20      | 1.35                            | 0.97                           | Down 0.38                       | 28.15                     |
|                | 20-30      | 1.31                            | 1.05                           | Down 0.26                       | 15.85                     |
| Former left skidding road | 0-10 | 1.36                            | 1.08                           | Down 0.28                       | 20.59                     |
|                | 10-20      | 1.23                            | 0.72                           | Down 0.51                       | 41.46                     |
|                | 20-30      | 1.28                            | 0.63                           | Down 0.65                       | 50.78                     |

Table 2. Changes in average soil density before and after installation of CD buildings and BIH in logged-over forests and former skidding roads.

After the installation of CD and BIH, the soil density on the skid trails decreased 0.2 - 1.20 g cm$^{-3}$, uneven, and depends on the depth of the soil. Decreasing soil density at a depth of 0 - 30 cm will cause root growth to develop correctly, so that nutrient and water uptake can increase, which in turn will also raise the growth of meranti seedlings planted on skid trails. Soil density in logged forests in the 0-10 cm layer decreased because the availability of organic material in the form of stems, branches, twigs and leaves that experience weathering or degradation increases, to improve soil density at depths of 0-10 cm. Meanwhile, soil density at a depth of 10 - 30 cm in logged forests actually increases. Presumably, this thing is due to the addition of increasing forest biomass so that soil density increases.

Based on Table 2 above, it can be concluded that the changes in soil density on skid trails before and after installation of CD and BIH as long as one year is very striking (decreasing 0.2-1.20 g cm$^{-3}$) and developing into regular soil.
3.1.2. Soil permeability. Table 3 showed that at a depth of 20-30 cm, the permeability has increased due to the formation of more soil pores as a result of increasing soil microbial activity. The soil microbes degrade litter that is included in the BIH. Meanwhile, permeability at depths of 0-10 cm and 10-20 cm varies depending on the position on the skid trail. Permeability in the middle of the skid trail increases while permeability on the left and right of the skid trail decreases.

Table 3. Changes in average permeability before and after installation of CD buildings and BIH on skidding road.

| Research sites          | Depth (cm) | Before treatment (cm hour\(^{-1}\)) | After treatment (cm hour\(^{-1}\)) | Change (down/ up) (cm hour\(^{-1}\)) | Percentage up / up (%) |
|-------------------------|------------|-------------------------------------|------------------------------------|-------------------------------------|------------------------|
| Logged                  | 0-10       | 3.13                                | 8.70                               | Up 5.57                             | 177.95                 |
|                         | 10-20      | 7.85                                | 5.96                               | Down 1.89                           | 24.08                  |
|                         | 20-30      | 2.05                                | 3.55                               | Up 1.50                             | 73.17                  |
| Former right skidding   | 0-10       | 8,075                               | 5.58                               | Down 2.50                           | 30.96                  |
| roads                   | 10-20      | 2.39                                | Down 1.99                          | 46.55                               |
|                         | 20-30      | 4.275                               | 7.32                               | Up 2.76                             | 60.53                  |
| Former middle skidding  | 0-10       | 6.84                                | 2.47                               | Down 4.37                           | 63.89                  |
| roads                   | 10-20      | 8.61                                | Up 3.56                            | 87.90                               |
|                         | 20-30      | 4.05                                |                                    |                                     |
| Former left skidding    | 0-10       | 17.24                               | 3.48                               | Down 13.76                          | 79.81                  |
| roads                   | 10-20      | 12.37                               | 8.62                               | Down 3.75                           | 30.32                  |
|                         | 20-30      | 11.86                               | 12.03                              | Up 0.17                             | 1.43                   |

The relationship between soil density and soil permeability on skid trails in this study is presented in Figure 1.

![Graph showing the relationship between soil density and soil permeability](image)

**Figure 1.** The relationship between soil density and soil permeability on skid trails before and one year after BIH and CD installation.

Figure 1 showed that before BIH and CD installation, each soil density increases by 1 g cm\(^{-3}\), the soil permeability decreases by 7,111 cm hour\(^{-1}\). However, one year after BIH and CD installation,
each increase in soil density by 1 g cm\(^{-3}\) will decrease the soil permeability at 4,595 cm/hour. Thus, the existence of BIH and CD increased soil permeability by 2,516 cm/hour or increased by 35.38%. Soil permeability on skid trails after BIH and CD pairs has increased by 35.38%. This better soil permeability happens because water can enter through the BIH and also because the BIH contains dried leaves and charcoal powder so that the microbial activity also increases. The charcoal powder will function as an element of soil ameliorant, which can absorb nutrients and slowly provides the nutrient to plants that grow around BIH. Besides, the BIH can accommodate sedimentation in the form of sand, dust and nutrients from the degradation of organic matter.

Based on the equation \(Y = -13,161x + 20,669\) (before the installation of BIH and CD) with \(Y = -20,272x + 25,264\) (after the installation of BIH and CD) the intersection of \(P (0.65, 12.2)\) is obtained. The cutoff point is a turning point for changes in soil density that strongly supports the soil permeability on skid trails, i.e., at a soil density of 0.65 g/cm\(^3\) and permeability of 12.2 cm/hour. This can be used as one of the important considerations in rehabilitating skid trails. Skid trail soil with soil density of 0.65 g/cm\(^3\) is included as normal soil, so the roots of seedlings planted on the skid trail will grow well. This means that the BIH and CD are effective in improving soil density on skid trails.

According to [19], results of soil permeability testing at the University Hasanudin, Makassar, Indonesia, showed that the average soil permeability was 0.00112 cm/s. Water infiltration volume from rainfall and domestic waste is recorded as much as 97.57 cm\(^3\)/sec. An area of water absorption in LRB cube as much as 8.73 m\(^2\) is required to absorb the water. If converted to LRB cube size, it will take about 8 m wide by 0.5 m and a depth of 0.5 m.

### 3.1.3. Soil moisture content

Soil moisture content in pF1 is water condition in the soil after experiencing flow due to gravity, while pF 2.54 is a field capacity, which is the maximum amount of water that can be absorbed by plants. Moisture content has changed due to skid trails. The results of measurements of soil moisture content and field capacity in logged-over forests and skid trails are presented in Table 4.

| Location               | Depth (cm) | Moisture Content (vol %.) |
|------------------------|------------|--------------------------|
|                        |            | pF1                      | pF2.54                   |
| Logged-over forest     | 0-10       | 53.41 ± 0.58             | 37.13 ± 0.49             |
|                        | 10-20      | 44.28 ± 0.57             | 30.44 ± 0.26             |
|                        | 20-30      | 44.32 ± 0.51             | 31.83 ± 0.31             |
| Former skidding roads  | 0-10       | 44.11 ± 0.68             | 31.86 ± 0.43             |
|                        | 10-20      | 43.39 ± 0.37             | 30.28 ± 0.47             |
|                        | 20-30      | 43.78 ± 0.37             | 31.43 ± 0.50             |

Table 4 showed that moisture content in logged-over forests at depths of 0-10 cm is greater (53.41 ± 0.58%) than that on skid trails (44.11 ± 0.68%). This is due to changes in land use from forests to skid trails. The moisture content at depths of 10-20 cm and 20-30 cm changes are not striking even almost the same (43.39 ± 0.37%). Moisture content on skid trails at depths of 0-10 cm (44.11 ± 0.68%) up to 20-30 cm is not too different. In such circumstances, the physical nature of the soil changes marked by decreasing soil porosity so that soil permeability also decreases.

The moisture content of pF 4.2 in logged-over forests at depths of 0-10 cm was 37.11 + 0.49% while on skid trails was 31.86%. The decline was caused by a change in land use from forest to skid trail. The value of field capacity at a depth of 10-30 cm in both logged-over forests and skid trails (30.28 - 31.86 vol) did not change much. This means that the moisture content and field capacity on the skid trails did not change much during the one year after the BIH and CD treatment.
3.2. Soil chemical properties

The results of the analyses of the chemical properties of soils on skid trails and logged-over forests generally show that the chemical properties of soils on skid trails are lower than those at logged-over forests. This is connected to the position of the skid trail that was built on horizon C, which is infertile, rocky, and does not contain organic matter. Increasing soil fertility, CEC and pH on skid trails is crucial for successful planting with intensive enrichment techniques.

Overall soil pH KCl on skid trails showed very low to low (4.73-5.30) conditions. The soil pH values in logged-over forests are lower (4.37 - 4.88) than the pH H₂O values on skid trails (5.20 - 5.30). The pH value in logged-over forests is low because there are still forest litter and humus that contain humic acid. Soil pH values describe the reaction of dissolved solutions of mineral nutrients to be used by plant roots. The pH value in this study was lower than the optimum soil pH value and tended to be more acidic in logged-over forests. According to [20] most of the soils in Indonesia are in the acid category with a pH range of 4.0-5.5.

The organic matter content in logged-over forests is higher (3.09%) compared to that on skid trails before (2.04%) and after one year (1.16%). This is due to the production of organic material by logged-over forests, which is still running well and is supported by a good decomposition process. [20] stated that the sulfur (S) of organic matter levels plays an essential role in soil fertility because it acts as a nutrient reserve, especially nitrogen (N), phosphor (P) and sulfur (S). Those nutrients are agents for improving soil structure, increasing the ability of the soil to retain water and nutrients (increase the level of cation exchange capacity (CEC) soils) and energy for microorganisms.

Organic matter can increase the cation exchange capacity two to thirty times higher than colloidal minerals, which account for 30 to 90% of the absorbent power of mineral soil. The increase of CEC due to weathering organic material will produce humus (organic colloids), which have a surface area that can hold nutrients and water so that it can be said that organic material can store fertilizer and water that is given in the soil. The increase in CEC increases the ability of the soil to retain nutrients.

On the skid trail, organic C increased from 1.16% to 2.04% (<3%). An increase in organic C on the skid trails after one year was suspected because there was litter input from the logged-over forest stands around the skid trails. The parameters of the C/N ratio in this study were smaller than 20 and based on the assessment of soil fertility criteria according to [21] that the C/N ratio in logged-over forests after one year is high (18.1). [22] stated that the C/N ratio is too small, so the nutrient cycle takes place quickly because organic matter decomposes, and there is an increase in N mineralization.

If the organic material has a high lignin content, the speed of N mineralization will be inhibited. Lignin is a polymer compound in woody plant tissue, which fills cavities between plant cells, thus causing plant tissue to become hard and challenging to overhaul by soil organisms. In woody tissue, lignin content can reach 38% [23]. Lignin overhaul will affect soil quality concerning topsoil composition. Twigs, branches and wood contain much lignin. In this study, no branches were found in the skid trails that had not been decomposed so that the addition of nutrients or C/N from the branches and wood was tiny.

CEC value in this study showed that CEC on the skid trails was lower than in natural forests (11.06 meq/100 g), but CEC in the BIH was higher (Figure 2) than CEC in natural forests (19.87 meq /100 g). This means that the presence of BIH can increase soil fertility in BIH with high fertility criteria, while on the skid trails, it was included in low fertility criteria. A high CEC can absorb and provide nutrients better than soil with a low CEC. The more cations that are exchanged in the soil, the less nutrient content that will be easily washed away by water.
Figure 2. Results of soil chemical analysis CEC (left) and C-organic (right) on a former skid trail, natural forest and BIH. (SR=Skidding Road, NF=Nature Forest, BIH=Biopore Infiltration Hole).

C-organic in the former skid trails after CD and BIH treatment increased by 43.21% while in BIH increased by 461% compared to C-organic in the former skid trails before treatment. The amount of increased C-org in the BIH is caused by the addition of litter and wood charcoal. C-org in BIH is also higher than in logged-over forests.

Figure 3. Results of P-available analysis on former skid trails, logged-over forests and BIH.

The results of the analysis of P-available in the former skid trail after treatment (SR2) increased by 16.32%. In comparison, the P-available in BIH increased by 37% compared to SR1 (former skid trail before treatment (Figure 3). It means that the presence of CDs and BIHs can increase the availability of P nutrients in the BIH, which is useful to support the growth of meranti plants in the planting hole.

The same thing happened to base saturation (BS) with a low category where the value was below 100% (20-37%). This value indicates that the land on the former skid trails and in natural forests is not dominated by bases that are mostly needed by plants. The results of the analysis of total N and Ca are presented in Figure 4.
The results showed that Ca in the BIH was much higher than in the former skid trails, both before and after treatment, as well as in logged-over forests.

4. Conclusion
Installation of cross drains (CDs) and biopore infiltration holes (BIHs) could improve the physical properties of soil, i.e., the density and permeability of soil and chemistry (CEC, CG, N, P, Ca, Na). It can also reduce soil density, increase soil permeability and soil fertility at a skid trail.

Biopore infiltration holes that contain litter and wood charcoal can improve microbial activity in the soil so that the soil chemical properties on skid trails become improved.

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