The effect of bio-retention hole application on soil physical properties and productivity and quality of *Tea sinensis* leaf

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**Abstract.** One of the critical problems for crop plantation on dry land is lack of water, especially in the dry season, including tea leaves. Proper treatment is required to solve the negative drought impact. The research aims to examine the effect of Bio-Retention Hole (BRH) on some of soil physical properties and the production and quality of tea leaves at one tea plantation in Cianjur Regency. The results showed that the application of BRH can improved soil aeration, reduced bulk density, increased total soil pore, infiltration, soil permeability and soil aggregate stability. The increase in organic matter is thought to be one of the main causes of the improvement in various physical properties of the soil. Plots treated with BRH showed a significant increase in organic matter. The BRH application increases the production and quality of tea leaves. The monthly tea leaves production in plots with the BRH application is higher than without BRH, averaging around 20 percent with variations of 5 to 100 percent. The level of Tanin substances which is used as an indicator of the quality of tea leaves is also about 20 percent higher in plots with the BRH application compared to without BRH.

**Keywords:** Bio-Retention Hole, soil physical properties, leaf tea production, leaf tea quality, soil organic matter

**1. Introduction**

Tea commodities are one of the commodities of Indonesia's plantation sector. Tea plant is generally grown in areas with altitudes above 700 m above sea level and many of which are found in areas of dry land with steep slopes. Dry land is land that needs water to meet its plants depending on rainwater and has never been permanently flooded in a certain period of time, in a year or throughout the year [1, 2, 3]. Dry land is one of the agro ecosystems that has great potential for agricultural businesses [4]. The abundant rain water in the rainy season only a small part enters the soil to fill underground water and much of it flows as surface runoff, which can cause erosion and drought problems in dryland agriculture, as well as flooding and sedimentation in the downstream area. Optimal use of rainwater is a crucial problem on dry land. Some important environmental factors that limit plant growth are water shortages [5]. Efforts should be made to conserve soil and water to increase the ability of soil to absorb water and control surface flow during the rainy season.

The Bio-Retention Hole (BRH) technique application is one way to improve the ability of the soil to absorb water into the soil so that it can increase soil moisture and soil water reserves and reduce...
surface runoff. Thus, the application of BRH on agricultural land, especially dry land, can increase water supply for plants, suppress erosion and loss of soil nutrients and increase plant growth and production [6, 7, 8, 9, 10]. The BRH application can increase the formation of small natural tunnels (bio-pore) produced by soil organisms and plant roots. The hole of the BRH application has a diameter of about 10 centimeters with a depth of up to 1 meter. If shallow groundwater is found, the depth of BRH does not exceed the groundwater level. Making BRH and filling it with the rest of the dead plants and organic waste, is considered effective to improve the ability of the soil to absorb water, suppress surface flow and increase the activity of soil organisms that are very useful for soil loosening, especially those around the holes produced by BRH application [11]. Furthermore, the benefits obtained from BRH applications are: 1) improving soil ecosystems; 2) prevent flooding; 3) increase groundwater reserves; 4) overcoming drought; 5) facilitating waste handling; 6) convert waste into compost; and 7) overcome problems caused by inundation [11].

The advantages of natural small tunnels (bio-pore) produced by BRH applications compared to macro pores between soil aggregates produce by soil tillage include: 1) more stable because it is coated with organic compounds released by the worm's body, 2) cylindrical holes that are continuous and not easily covered by the development process because even wetting of the soil which is vertic (expanding/shrinking), 3) can provide burrows that are easily penetrated by plant roots, and 4) provide channels for infiltration smooth into the ground [11].

The purpose of this study was to assess the benefits of BRH applications in improving soil properties especially those related to supply of available water for plant and movement of water in the soil and the production of fresh tea leaves and the quality of tea. Some soil properties, especially the physical properties of soil, greatly influence the processes related to BRH and their effects, especially soil texture, soil organic matter, soil bulk density, total porosity, and pore size distribution, soil permeability, and infiltration capacity.

2. Method

2.1. Time and location of research
The study was conducted in June 2015 until April 2016 on private tea plantations (PT. Sumber Daun Putri) in Pasawahan Village, Takokak District, South Cianjur Regency, including collecting soil and Tea leaf samples. Soil properties analysis was carried out in Soil and Water Conservation Laboratories, Faculty of Agriculture, IPB University. The contents or levels of catechins (tannins) of Tea leaf measured at the Agriculture Industry Engineering Laboratory, IPB University. The method used to measure catechins (tannins) contents is method.

2.2. Making Bio Retention Hole BRH
To assess the effect of BRH, 5 (five) plots are built in the research location where each plot measuring 10 x 10 m and each plot contains 100 tea trees inside. Those five plots consist of: 1) P0 (Control Plot, is a plot not given the BRH treatment, 2) P1 is plot of the BRH treatment which has slope around 5-8%, 3) P2 is plot of the BRH treatment which has slope around 9-12%, 4) P3 is plot of the BRH treatment with slope around 13-16%, and 5) P4 is plot of the BRH treatment with slope around 17-20%. P0 serves as a benchmark for comparing the content of soil texture, soil organic matter, and the weight of fresh tea leaf production as well as the quality of tea with four experimental plots given BRH treatment. Soil sampling for analysis of several soil physical properties (soil bulk density, total porosity, pore space distribution, permeability, and infiltration capacity) before and after BRH treatment was carried out to see the effect of BRH application for 10 months. While sampling to analyze the content of soil texture, soil organic matter, and the nature of production and quality of tea was carried out in the 10th month in plots P0, P1, P2, P3 and P4.

In plots P1, P2, P3 and P4 that get BRH treatment, each tea tree is surrounded by 4 (four) BRHs (see Fig. 1). The location or position of BRHs are on the north, south, west, and east parts with a
distance of 0.25 meters from the tea plant (see Fig.1). Each plot has a total of 100 tea plants, so it contains of 400 BRHs filled with leaf litter, stalks and other plant debris.

![Figure 1. Position of Bio-Retention Holes (BRH) around the tea plant.](image)

**Figure 1.** Position of Bio-Retention Holes (BRH) around the tea plant.

### 2.3. Methods
Observation of soil physical properties was carried out in the field all together with collecting undisturbed (core) and disturbed soil samples at a depth of 0 - 20 cm for determination of soil texture, soil organic matter content, soil bulk density, pore size distribution and total porosity, and disturbed soil samples were carried out using a sample ring at a depth of 0-20 cm and a depth of 20-40 cm. The properties of the soil and Tea leaf analysed and the methods used are presented in Table 1.

| Tea Leaf and Soil Parameters | Analytical method                                      |
|-----------------------------|--------------------------------------------------------|
| Soil                        | Laboratory (Pipette)                                    |
| - Texture                   | Laboratory (Walkey and Black)                           |
| - Organic matter            | Laboratory (Gravimetric)                               |
| - Bulk Density              | Laboratory (Membrane and Pressure Plate Apparatus)     |
| - Pore size distribution and Total Porosity | Laboratory (Constant Head) |
| - Permeability              | Field observation (Double Ring Infiltrometer)           |
| - Infiltration Capacity     | Field observation (Gravimetric-weighing)                |
| Tea Leaf                    | Laboratory (Spectrophotometric)                         |
| - Fresh weight              |                                                        |
| - Catechins (tannis)        |                                                        |

### 2.4. Data analysis
Experimental design on organic material data, soil texture, soil bulk density, total porosity, soil pore distribution, soil permeability, infiltration capacity, fresh Tea leaf production and catechins (tannis) content were tested using variance test (ANOVA) at a range of 5% to see the effect of treatment on land and if there is a real effect on the parameters observed the treatment is compared using a further
test with the Duncan Multiple Range Test (DMRT) method using SAS for Windows version 19.0 software.

3. Result and Discussion
The BRH application has an influence on some soil properties and the production of fresh tea leaves and the quality of tea. The effect varies from insignificant to very significant.

3.1. Soil organic matter
The BRH treatment (P1 to P4 plots and average) can significantly increase the content (see Fig. 2). Besides being able to reduce surface flow and erosion of the top layer containing the largest soil organic matter, the BRH treatment also incorporates plant debris (litter) into the BRH hole. BRH holes filled with plant debris will increase the activity of soil organisms. Thus an increase in soil organic content due to BRH treatment can be understood. P1 plot with the smallest slope have the highest and lowest soil organic matter content was on P4 plot which has the largest slope. The greater the slope, the greater the erosion of the topsoil, the lower the level of soil organic matter.

![Soil Organic Matter Content in Plots of BRH Treatment](image)

**Figure 2.** The soil organic matter content of plots of Bio-Retention Holes-BRH (P1-P4 and average) as compared to before/without BRH (P0).

3.2. Soil Texture
Soil texture data presented in Table 2 are more to give information about distribution of soil particles in each plot. Soil texture is a physical property of soil that is very difficult to change so that if the plots of soil are different then the difference is not caused by the treatment of BRH. The difference in soil texture may be due to the level of soil erosion triggered by the different slope of the land. P4, which has the steepest slope, has the lowest clay content and the roughest texture class compared to other plots with a smaller slope.
### Table 2. Distribution of soil particles (soil texture) in control and plots under BRH treatments.

| Treatment    | Sand   | Silt    | Clay    | Texture Class          |
|--------------|--------|---------|---------|------------------------|
| Control      | 14.95  | 50.67   | 34.39   | Silty clay loam        |
| P1-BRH       | 16.14  | 53.86   | 30.00   | Silty clay loam        |
| P2-BRH       | 20.93  | 40.37   | 38.70   | Silty clay loam        |
| P3-BRH       | 22.11  | 29.45   | 48.44   | Silty clay             |
| P4-BRH       | 27.78  | 47.93   | 24.29   | Silty loam             |

### 3.3. Soil Bulk Density (SBD)

Overall the BRH treatment did not affect soil bulk density (see Table 3). All research sites or plots have very low soil bulk density because they are classified as Andosol Soil so it will be very difficult to reduce soil bulk density anymore.

### Table 3. Effect of BRH on soil bulk density.

| Treatment    | Replication/ Block | Soil Depth (cm) | Average  |
|--------------|--------------------|-----------------|----------|
| Before BRH   | P1                 | 0-20            | 0.56b    |
|              | P2                 | 0.56b           | 0.49b    |
|              | P3                 | 0.48a           | 0.54a    |
|              | P4                 | 0.85d           | 0.78d    |
| After BRH    | P1                 | 0.65b           | 0.55b    |
|              | P2                 | 0.61b           | 0.51b    |
|              | P3                 | 0.68b           | 0.56b    |
|              | P4                 | 0.76c           | 0.68d    |
| Before BRH   | Average            | 0.63b           | 0.59b    |
| After BRH    | Average            | 0.66b           | 0.59b    |

Notes: Numbers followed by the same letters on the same column show no significant difference according to Duncan's Test at the level of 5%.

### 3.4. Total porosity and pore distribution

The BRH treatment significantly increased total porosity and field capacity and has no effect on the total drainage pores (macro pores) and available water pores. Overall the BRH treatment did not significantly influence the total drainage pores, but the BRH treatment significantly increased the very fast drainage pore and reduced the fast and slowly drainage pores (see Table 4). Addition of soil organic matter provided in plots with BRH treatments can improve soil aggregation producing higher total porosity, field capacity and very fast drainage pores.

### Table 4. Soil pores before and after BRH treatment on all condition related to their soil water holding capacity or their pores distribution.

| Soil properties/ characteristics | Soil Depth (cm) | Before BRH | After BRH |
|----------------------------------|----------------|------------|----------|
| Saturated Condition (%v)         | 0 – 20         | 76.94d     | 74.53c    |
|                                  | 20 – 40        | 80.51a     | 78.90c    |
| Average                          |                | 78.72b     | 78.90c    |
| Field Capacity (% v)             | 0 – 20         | 32.88d     | 30.60b    |
|                                  | 20 – 40        | 38.01a     | 40.03b    |
The effect of the BRH treatment on increasing constant infiltration rate is presented in Table 6. Plots with the BRH treatments have higher soil organic matter content, soil porosity and very fast drainage. The BRH treatment significantly increase soil permeability (see Table 5). Increased SOM and activity of soil organisms due to the treatment of BRH will produce more large-sized pores (very fast pore drainage) which ultimately increase soil permeability.

| Treatment | Replication/ Block | Soil Depth (cm) | Average |
|-----------|-------------------|----------------|---------|
| Before BRH | P 1 | 8.32 | 10.90<sup>a</sup> | 9.61<sup>a</sup> |
| | P 2 | 7.53 | 5.91<sup>a</sup> | 6.72<sup>a</sup> |
| | P 3 | 13.01 | 11.20<sup>b</sup> | 12.10<sup>b</sup> |
| | P 4 | 9.68 | 13.16<sup>b</sup> | 11.42<sup>b</sup> |
| After BRH | P 1 | 56.67<sup>b</sup> | 42.76<sup>b</sup> | 49.72<sup>c</sup> |
| | P 2 | 48.35<sup>b</sup> | 5.52<sup>c</sup> | 26.93<sup>b</sup> |
| | P 3 | 84.90<sup>b</sup> | 33.44<sup>b</sup> | 59.17<sup>c</sup> |
| | P 4 | 55.00<sup>b</sup> | 55.37<sup>b</sup> | 55.19<sup>b</sup> |
| Before BRH | Average | 9.64<sup>a</sup> | 10.23<sup>ab</sup> | 9.94<sup>b</sup> |
| After BRH | Average | 61.23<sup>b</sup> | 34.27<sup>ab</sup> | 47.80<sup>bc</sup> |

Notes: Numbers followed by the same letters on the same column show no significant difference according to Duncan’s Test at the level of 5%.

3.5. Soil permeability
The BRH treatment significantly increased soil permeability (see Table 5). Increased SOM and activity of soil organisms due to the treatment of BRH will produce more large-sized pores (very fast pore drainage) which ultimately increase soil permeability.

| Soil properties/characteristics | Before BRH | After BRH |
|--------------------------------|------------|-----------|
| Permanent Wilting Point (% v) | Average | 35.44<sup>a</sup> | 39.72<sup>b</sup> | 43.14<sup>b</sup> | 35.86<sup>b</sup> | 42.14<sup>b</sup> | 44.40<sup>b</sup> | 51.63<sup>b</sup> | 41.40<sup>b</sup> |
| Drainage/Macro Pore (%v) | 0 – 20 | 19.53<sup>a</sup> | 22.22<sup>a</sup> | 25.34<sup>b</sup> | 32.13<sup>bc</sup> | 37.47<sup>c</sup> | 39.18<sup>c</sup> | 30.32<sup>b</sup> |
| | 20 – 40 | 44.06<sup>a</sup> | 42.50<sup>a</sup> | 38.03<sup>bc</sup> | 33.80<sup>bc</sup> | 33.94<sup>bc</sup> | 28.36<sup>bc</sup> | 23.93<sup>bc</sup> | 28.21<sup>bc</sup> |
| -Very Fast Drainage Pore (%v) | Average | 43.28<sup>a</sup> | 41.51<sup>bc</sup> | 36.60<sup>bc</sup> | 34.81<sup>bc</sup> | 36.99<sup>bc</sup> | 34.59<sup>bc</sup> | 27.27<sup>bc</sup> | 32.96<sup>bc</sup> |
| -Fast Drainage Pore (%v) | 0 – 20 | 16.00<sup>a</sup> | 14.20<sup>a</sup> | 13.56<sup>a</sup> | 11.92<sup>a</sup> | 26.15<sup>b</sup> | 21.02<sup>b</sup> | 10.39<sup>b</sup> | 22.08<sup>b</sup> |
| | 20 – 40 | 14.17<sup>bc</sup> | 16.31<sup>bc</sup> | 9.89<sup>a</sup> | 17.35<sup>cd</sup> | 29.13<sup>bc</sup> | 23.97<sup>cd</sup> | 18.50<sup>bc</sup> | 28.48<sup>cd</sup> |
| -Slow Drainage Pore (%v) | Average | 15.08<sup>bc</sup> | 15.25<sup>bc</sup> | 11.73<sup>a</sup> | 14.63<sup>bc</sup> | 27.64<sup>bc</sup> | 22.50<sup>bc</sup> | 14.45<sup>bc</sup> | 25.28<sup>bc</sup> |
| Available Water Pore (%v) | Average | 14.35<sup>c</sup> | 13.77<sup>c</sup> | 13.11<sup>c</sup> | 11.06<sup>c</sup> | 6.34<sup>c</sup> | 6.07<sup>c</sup> | 7.28<sup>c</sup> | 4.38<sup>c</sup> |

Numbers followed by the same letters on the same column show no significant difference according to Duncan’s Test at the level of 5%.

3.6. Infiltration capacity
The effect of the BRH treatment on increasing constant infiltration rate is presented in Table 6. Plots with the BRH treatments have higher soil organic matter content, soil porosity and very fast drainage.
pore that might produce higher constant infiltration rate. The effect of the BRH on infiltration capacity curves is shown in Fig 3.

**Table 6.** The effect of BRH on constant infiltration rate in the four plots.

| Treatment               | P1  | P2  | P3  | P4  | Average |
|-------------------------|-----|-----|-----|-----|---------|
| Before BRH (cm/hr)      | 12  | 18  | 18  | 24  | 18 (F)  |
| After BRH (cm/hr)       | 18  | 24  | 24  | 25  | 23 (F)  |

Notes: Remarks: BRH = Bio-Retention Hole; M = moderate; F = fast

3.7. Quantity and quality of tea leaf

The effect of BRH treatment of fresh Tea leaf production is shown in Table 7. It is shown that the BRH treatment increased the fresh Tea leaf production, particularly in the month of June 2016 (see Fig 4).

**Figure 3.** The effect of BRH (Bio-Retention Holes) on Infiltration Capacity in Plot 1, 2, 3 and 4.
Table 7. The effect of BRH treatment on the production of fresh tea leaf.

| Treatment       | Production of 2015 (kg/ha) | Production of 2016 (kg/ha) |
|-----------------|----------------------------|----------------------------|
|                 | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Av  |
| Before BRH      | 418 | 420 | 302 | 241 | 198 | 308 | 476 | 288 | 386 | 358 | 397 | 422 | 351 |
| After BRH       | 443 | 440 | 306 | 356 | 367 | 404 | 412 | 418 | 446 | 480 | 563 | 900 | 461 |

While the effect of BRH treatments on the quality of fresh Tea Leaf production is illustrated in Fig 5. The quality of Tea leaf is represented by their catechins (tannins) content that are the dominant polyphenolic compounds in tea. Catechins (tannis) are important compounds that function as antioxidants and determinants of tea products [12]. The properties of tea determined by catechins (tannins) are aroma, taste, and color of tea.

Figure 4. The effect of Bio-Retention Holes (BRH) treatment of the fresh tea leaf production.

Figure 5. The effect of Bio-Retention Holes (BRH) treatment on the tea leaf quality represented by their catechin (tannin) content.
4. Conclusion
The Bio-Retention Holes (BRH) treatments on soil properties were able to increase significantly soil organic matter content, total soil porosity and very fast drainage pores. The BRH treatments on tea leaf were able to increase the fresh tea leaf production and improve tea leaf quality which is indicated by increasing of their catechin (tannin) content. In other words, the BRH treatments can improve soil conditions as well as the quantity of fresh tea leaf production and the quality of tea leaf.

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