Ameliorating Sandy Soil Properties: Application of Mathematical Model to Explore Spinach (*Amaranthus tricolor* L.) Plant Response

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**Abstract.** Amelioration is an effort to increase soil fertility by manipulating chemical and physical properties of the soil. In this study, biochar and manure were adopted for ameliorating sandy soil. The purposes of this study were to identify the response of spinach plants, to apply mathematical model for exploring spinach plant growth, and to determine the appropriate ameliorant dosage. The ameliorant were rice husk biochar and poultry manure. The study was conducted in a greenhouse with 4 different dose comparisons (in kg; sandy soil: rice husk biochar: poultry manure), i.e. 1: 0: 0 (C), 1: 0.007: 0 (B), 1: 0.0035: 0, 0035 (MB1), and 1: 0.007: 0.007 (MB2). Each treatment was repeated 5 times in a Complete Block Design. Growth parameters observed were plant height, number of leaves, and plant weight. Observation was carried out for 70 days. The analysis used was one-way ANOVA test, Turkey test, logistic equation and exponential polynomials models, and linear regression. The study revealed that the best spinach growth response by MB1. The growth rate from plant height side of C, B, MB1, and MB2 treatments were - 0.0509, -0.0406, -0.0556, and - 0.0489 respectively. In terms of number of leaves, the optimum of growing period of C, B, MB1, MB2 treatments were 48, 65, 96, and 66 days after planting respectively. One-way ANOVA test showed that rice husk biochar and poultry manure ameliorant had a significant effect on plant growth both height and number of leaves (sign. <0.05). While, the wet and dry weight were not significantly effect (sign. > 0.05). Mathematical model with logistic and exponential equations were acceptable to describe spinach plant growth (R2> 80%). Ameliorant rice husk and poultry naure 5 tons ha/ha (MB1 treatment) was recommended for optimum spinach growth in sandy soil.

**1. Introduction**

Marginal sandy soil has a poor quality from agricultural aspect [1]. Underlined that sandy soil contains low nutrient and less water for plant growth. Sandy soil is characterized by high infiltration rate and low water holding capacity but easy root penetration [2]. Confirmed the low water holding capacity of sandy soil caused by a large particle size that in range 0.05 to 2 mm. Furthermore, sandy soil has less phosphorus (5.1 to 20.5 ppm), organic material in range 0.4 to 0.8 %, and potassium in range 0.09 to 0.20%. These properties are less able to promote plant growth, so that soil manipulation must be involved to improve sandy soil properties both physical dan chemical quality.

Soil amelioration is a term used to describe an improvement in physical, chemical, biological, and mechanical properties. [3] clarified soil amelioration approaches typically involve either the strategic application of soil amendments, such as lime, dolomite, gypsum, organic matter or clay-rich subsoil, or
the use of deep tillage or, often, a combination of the two. It was stressed that soil amelioration is slow and costly, so it is necessary to have long-term benefits to achieve a good return on the investment.

Studies on the effect of soil amendments such as biochar [4,5] and manure [5,6] on soil properties and plant growth have been frequently carried out in tropic [7] and sub tropic [8]. However, less study on the effect of soil ameliorating to plant response by growth rate indicator. Mathematical model can be applied to explore plant response as adjustment to environment changing [9] such as amelioration of sandy soil. [10] argued that plant growth model used to apply for accurately predicting plant response in different climate, soil, and other environmental conditions. The main objective of this this study was to explore effect of amelioration on sandy soil to spinach (Amaranthus tricolor L.) growth. Some activities were conducted to identify the plants response, to apply mathematical model in determining growth rate, and to determine the appropriate ameliorant dose.

2. Materials and Method
An experimental study in a greenhouse scale was design to determine the plant response due to the amelioration of sandy soil. A set micro climate equipment was set in green house to record maximum and minimum temperature, relative air humidity, and solar radiation (Thermohygrometer KW06 797 and Solarimeter DBTU 1300). Disturbed sandy soil samples were collected from top soil (0-20 cm) of coastal land in Southern part of Bantul regency, special region Yogyakarta, Indonesia. Amelioration of sandy soil used rice husk biochar and poultry manure. The biochar was produced by pyrolysis, while poultry manure was obtained from chicken breeder. The study applied ameliorating treatment: i) biochar dose 10 ton/hectare, ii) biochar and manure dose 5 ton/ hectare, iii) biochar and manure dose 10 ton/hectare, and iv) control (sandy soil). Table 1 presents detailed of the treatment. Ratio of soil and ameliorant refers to [10]. The soil and ameliorant were mixed and put in polybag whose 20 x 20 cm (diameter, high) size. Each treatment was repeated 5 times and were set in a complete randomized block design as seen in Figure 1.

| Table 1. Composition of soil, biochar and manure |
|-----------------------------------------------|
| Treatment | Dosage of ameliorant (ton/hectare) | Ratio of soil and ameliorant (kg) (soil:biochar:manure) | Symbol |
| Control (C) | - | 1: 0 : 0 | |
| B | 10 | 1: 0.007 : 0 | |
| BM1 | 5 | 1: 0.0035: 0.0035 | |
| BM2 | 10 | 1: 0.007: 0.007 | |

Fourteen days old spinach (Amaranthus tricolor L.) seed were planted in each polybag at different treatments. Firstly, the soil samples in each polybag were collected for physical and chemical properties test (texture, structure, particle density, bulk density, porosity, pH, C-organic, N total, available phosassium (K), and P2Os). Soil thermometer were installed at depth 5, 7.5, and 10 cm from ground of polybag. To avoid water stress, irrigation and drainage were applied to every treatments in same condition. Plant growth (height, number of leave) was measured every 3 days, while micro climate and soil thermal were recorded daily. The measurement was stopped when spinach flowering. Later, spinach plants were harvested. Latest, wet and dry biomass was measured.
Statictive descriptive (max, min, stdev, average, homogenity test) was applied to initiate data analysis. Homogeneity test was conducted before crop mathematical modeling. The crop modeling [11] produces a coefficient which informs rate of plant growth ($\mu$). Here, crop modeling used Logistic equation (Eq.1-Eq. 5) and Exponential Polynomial equation (Eq. 6 & Eq.7) to determine plant response in sandy soil with rice husk biochar and poultry manure ameliorants. Determination coefficient ($R^2$) was used to validate the crop modeling. Later, oneway Anova was used to evaluate the differences of the ameliorant treatment focused on the rate of plant growth, wet and dry biomass weight.

\[
\frac{dW}{dt} = \mu \cdot W \left(1 - \frac{W}{W_f}\right) \\
\frac{1}{W} \frac{dW}{dt} = \mu \left(1 - \frac{W}{W_f}\right) \\
\int_{W_f}^{W_0} \frac{dW}{W} = \int_0^t \mu \, dt \\
\ln \frac{W_0}{W_0-(W_f-W_0)} = \mu \cdot t + C \\
W = \frac{W_0}{W_0+(W_f-W_0)e^{\mu t}} \\
W = \exp(a_0 + a_1 t + a_2 t^2 + \cdots) \\
\ln W = (a_0 + a_1 t + a_2 t^2 + \cdots) 
\]

3. Results and Discussion

3.1. Soil properties

Result of soil texture analysis by using Hydrometer method shown in Table 2. Sand fraction was more than 60% while clay less than 2%, so it classified as sandy soil. Particle density of the soil was range 2.50 to 2.69 g/cm$^3$ as seen in Table 3. [12] argued that particle density ($\rho_s$) of mineral soil is about 2.65 g/cm$^3$. It is an internal property which can not be modified by physical and chemical treatments. Contrary, bulk density ($\rho_b$) and porosity (N) are dynamic properties of soil due to the change of soil structure and aggregation. In case mineral soil, bulk density is range 1.20 to 1.85 g/cm$^3$ [13]. Table 2 showed the alteration of bulk density and porosity of the soil every ameliorant treatment. [14] noticed that application of poultry manure reduced soil bulk density and increase porosity of Sorghum area in Southwest Nigeria. [15] proved that long-term manure applications in agricultural soil cause increases porosity, infiltration capacity and decreases in bulk density. In this study, the soil ameliorating by rice husk biochar and poultry manure likewise decrease the bulk density and rise the porosity (Table 3).
Table 2. Percentage of silt, clay and sand fractions as result of Hydrometer method

| No. Of sample | Texture class | Percent of | silt   | clay | sand  |
|---------------|---------------|------------|--------|------|-------|
| 1             | Sandy         | 36.56      | 2.81   | 60.62|
| 2             | Sandy         | 11.25      | 0.00   | 88.75|
| 3             | Sandy         | 2.81       | 5.63   | 91.56|
| 4             | Sandy         | 8.44       | 0.00   | 91.56|
| 5             | Sandy         | 11.25      | 0.00   | 88.75|
| Average       |               | 14.06      | 1.69   | 84.25|

Chemical properties of soil were presented in Table 3. The last chemical properties (after harvesting) has not analyzed yet. However, it showed that pH (H₂O) was normal (5.58 to 6.58), C-organic content was range 0.49% to 0.66%, and N-total was range 0.01% to 0.04%. Another macro nutrient: photassium and phospor were range 75 to 159 ppm and 45 to 86 ppm, respectively.

Table 3. Physical and chemical properties of soil and its alteration by ameliorating

| Treatment | ρs (g/cm³) | ρb (g/cm³) | N (%) | pH (H₂O) | C-org (%) | N-tot (%) | K (ppm) | P₂O₅ (ppm) | ρb (g/cm³) | N (%) |
|-----------|------------|------------|-------|-----------|-----------|-----------|---------|------------|------------|-------|
| C         | 2.50       | 1.80       | 27.88 | 6.52      | 0.60      | 0.01      | 95      | 70         | 1.70       | 32.13 |
| B         | 2.69       | 1.77       | 23.56 | 5.87      | 0.49      | 0.03      | 159     | 64         | 1.47       | 45.42 |
| BM1       | 2.66       | 1.81       | 28.53 | 6.38      | 0.66      | 0.03      | 72      | 86         | 1.53       | 42.32 |
| BM2       | 2.67       | 1.76       | 26.96 | 6.58      | 0.49      | 0.04      | 86      | 45         | 1.55       | 42.04 |

3.2. Micro climate condition

Greenhouse was used for the study located in Faculty of Agricultural Technology Universitas Gadjah Mada. Micro climate condition during observation was presented in Table 4. Temperature was range 26.9°C to 38°C, relative air humidity 48.6%, and solar radiation 50.3%. [16] clarified that optimum climate condition for spinach growth is 20°C to 30°C with relative air humidity 60%. Environmentally, spinach growth in this study was obstacle d by relative air humidity. [17] stated humidity lower than growing condition lead to plant water stress that can reduce growth. The air humidity around plant must be keep at the right level so the plant will be able to keep its stomata open. Because promising the stomata open for photosynthesis is vital for biomass production.

Table 4. Average micro climate condition in green house during spinach growth observation

| Micro climate element | Value |
|-----------------------|-------|
| Max. Temperature       | 38.3  |
| Min. Temperature       | 26.9  |
| Air relatif humidity   | 48.6  |
| Solar radiation        | 50.3  |
| Soil temperature       |       |
| - Top soil (0-5 cm)    | 30.7  |
| - Middle (5 – 10 cm)   | 30.7  |
| - Lower (> 10 cm)      | 30.6  |
3.3. Plant response

3.3.1. Plant height. Homogeneity test for plant height was illustrated in Table 5. Block A, B, C, D, and E are repetition of spinach plant every treatment. Spinach were planted in block A were not homogenous in term of plant height, so the next analysis ignored the plant height data from block A. Figure 2 presented the height of spinach plant versus time. Trend of data in line with logistic equation. Based on Eq. 4, the rate of growth (µ) could be determined and the result seen in Table 6.

| Block | Homogenity value | Classification  |
|-------|------------------|-----------------|
| A     | 0.001            | Not homogenous  |
| B     | 0.389            | Homogenous      |
| C     | 0.142            | Homogenous      |
| D     | 0.065            | Homogenous      |
| E     | 0.412            | Homogenous      |

Figure 2. Spinach height versus time every ameliorant treatment

| Treatment | Growth rate (µ) | Sig T-test | Sig Turkey-test | R²     |
|-----------|-----------------|------------|-----------------|--------|
| C         | -0.0509         | 0.639      |                 | 0.98   |
| B         | -0.0406         | 0.071      |                 | 0.94   |
| BM1       | -0.0556         | 0.527      |                 | 0.98   |
| BM2       | -0.0489         | 0.616      |                 | 0.97   |

Ameliorating sandy soil used rice husk biochar (B) showed the rate of growth was the latest. [1] confirm that sandy texture was nutrient poor soil, so it demands more organic material to support plant growth. The poultry manure supplies organic material and it plays a role in pH as well. Biochar (B) caused the soil pH decreasing as seen in Table 3. Rice husk biochar worthwhile in reducing soil acidity [4] In this study, sandy soil has a normal pH (6 – 7). Application of biochar precisely decreased the pH, so the soil was more acid. Composite of rice husk biochar and poultry manure (BM1) by ratio soil, biochar, manure (in kg), was 1, 0.00035, 0.00035 respectively created a great impact on the height of plant (Table 6) even though the pH was decreased.
The rate of growth (µ) integrated in Eq. 5 to predict the plant height. Table 6 presented determination coefficient (R²). One sample T-test indicated 0.001, it means ameliorant had significant effect on plant height. Later, Turkey test was conducted and the result demonstrated that ameliorant biochar (B) and the composite of biochar and manure 5 ton/hectare (BM1) was significantly different. Whereas, the control (C) and composite of rice husk biochar and poultry manure 10 ton/hectare (BM2) was not significantly different. Based on R², logistic equation was excellent for plant height modeling on sandy soil with ameliorant of rice husk biochar and poultry manure.

3.3.2. Number of leaves. Generally, the main biomass consumption of spinach is leaves. Homogeneity test for number of leaves was presented in Table 7. It indicated that data on the number of leaves in every block were homogen, so they were used in the later analysis. Figure 3 illustrated the number of spinach leaves versus time. Trend of data in line with Exponential Polynomial equation. Based on Eq. 6, coefficient a₀, a₁, and a₂ could be determined and the result seen in Table 8. The coefficient integrated to Eq. 6 to predict the number of leaves. Hereinafter, the first order differentiation done to inform period when the maximum of number of leaves (Table 8). Then, it integrated to the Eq. 6 to calculate the maximum number of leaves. Table 7 showed that BM1 need 96 days (the longest period) to produce 19 leaves and it recorded as the most number of leaves. So, spinach plant in sandy soil with ameliorant of rice husk and poultry manure 5 ton/hectare could the best biomass production but harvest time will be the longest. When dose of biochar and manure increase, the spinach growth was less and it should be explored by comparing chemical properties at initial and end of the ameliorant treatment.

| Block | Homogenity value | Classification |
|-------|------------------|----------------|
| A     | 0.088            | Homogenous     |
| B     | 0.973            | Homogenous     |
| C     | 0.201            | Homogenous     |
| D     | 0.162            | Homogenous     |
| E     | 0.878            | Homogenous     |

Table 7. Homogenity test for data on number of spinach leaves in every block

Figure 3. Number of leaves versus time every ameliorant treatment
Table 8. Coefficient of exponential polynomial equation, period when the maximum of number of leaves, T-test, Tukey test and R² of spinach at different ameliorating treatment

| Treatment | a₂      | a₁      | a₀      | Period when maximum number of leaves (day after planting) / maximum number of leaves | Sig T-test | Turkey test | R² |
|-----------|---------|---------|---------|--------------------------------------------------------------------------------------|------------|-------------|----|
| C         | -0.0003 | 0.0390  | 1.1766  | 48 / 11                                                                               | 0.67       | 0.76        |    |
| B         | -0.0004 | 0.0385  | 1.4899  | 65 / 10                                                                               | 0.006      | 0.28        | 0.92|
| BM1       | -0.0002 | 0.0348  | 1.4241  | 96 / 19                                                                               | 0.49       | 0.93        |    |
| BM2       | -0.0003 | 0.0398  | 1.2929  | 66 / 14                                                                               | 0.67       | 0.80        |    |

3.3.3. Wet and dry biomass. Figure 4 showed wet and dry biomass every ameliorant treatment. Wet biomass of BM1 treatment (biochar and poultry manure 5 ton/hectare) was the heaviest, while control plants demonstrated less biomass. The BM1 treatment provided an optimum pH and organic material (C-organic) for spinach growth, so that photosynthesis run perfectly in biomass production. Biochar treatment detiorated soil pH which may affect absorption of abundant available photassium in soil (Table 3) and its impact on μ (the rate of growth in Table 6) as well as weight biomass (Figure 4). Based on oneway Anova test, significancy of wet and dry biomass were 0.549 and 0.427 respectively. When significancy > 0.05, then it denoted that rice husk biochar and poultry manure were not significantly effect to wet and dry biomass.

![Figure 4. Wet and dry biomass weight every ameliorant treatment](image)

3 Conclusion
Spinach (*Amaranthus tricolor* L.) response on sandy soil with biochar and poultry manure ameliorants was studied by mathematical model. Spinach height was modeled by logistic equation and it proved that growth rate of composition biochar and manure 5 ton/hectare (BM1) was the highest. The number of leaves was analyzed by applying polynomial equation. This revealed that the number of leaves of BM1 treatment was the most abundant but the harvest time was the longest. Later, it confirmed by biomass weight of BM1 treatment was the heaviest. Statistically, amelioration of sandy soil using rice husk biochar and poultry manure had a significant effect on plant growth both height and number of leaves but it did not affect the biomass weight. Mathematical model with logistic and exponential equations were acceptable to describe plant growth (R²> 80%). Compostion of rice husk and poultry manure 5 tons ha/ha (MB1 treatment) was recommended for spinach cultivation in sandy soil.
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