Physical and Chemical Properties of Soil at Degraded Primary Forest, Secondary Forest and Degraded Forest Land of Grand Forest Park Sultan Thaha Syaifuddin, Jambi

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Abstract

Effort to restore and rehabilitate degraded primary forest and secondary forest, as well as degraded land at Grand Forest Park (Taman Hutan Raya) Sultan Thaha Syaefuddin or Tahura Senami, Jambi needs complete pre- assessment of the biophysical condition of Tahura Senami and land. Although year-round temperature, solar radiation and humidity at Tahura Senami are conducive to rapid growth of planted trees, often limiting factor is soil fertility. The objective of this paper is to evaluate the physical and chemical properties of soil at Tahura Senami, in order to develop a science-based soil management as part of the silvicultural practice. At each land-use type, an either transect or plot were made and soil samples were taken at randomly selected points, either along transect, or within a plot, at 0 – 20 cm and 20 – 40 cm depth. Dominant soils are red yellow podzolic (70%), which has average bulk density (0.91-1.42), normal porosity (49.18%-65.78%) and permeability to water (2.11-13.18 cm/hr). From the percentage of silt (12.68%-43.18%) and clay (19.28%-42.35%), the soil can be classified as sandy loam to light loam. The soils have percentage of C-organic and N-content ranging from 0.53-3.36 and 0.05-0.26, respectively. The chemical properties of red-yellow podzolic or Ultisols/Oxisols, however, pose many constraints for plant growth. Main limiting factors for plant growth are low pH (4.20–5.25) and low available essential nutrients, i.e. P (6.40-14.30 ppm), K (0.04-0.30 me/100g), Ca (0.58-2.48 me/100g) and Mg (0.16-0.56 me/100g). Although soil exchange capacity (6.16-13.56 me/100g) is moderate, degree of base saturation (7.60-28.99%) is relatively low. Plantation establishment, such as restoration, and rehabilitation activities, or agroforestry, would require intervention into soil fertility to achieve well grown plants. Intervention can be done in the form of improvement of soil pH by adding lime, conservative field preparation, and fertilizers application.

Key words: soil physical properties, soil chemical properties, degraded forest land

Introduction

Background

Degraded primary forest and secondary forest as well as degraded land in Indonesia have given a strong call for immediate action of rehabilitation and restoration. Many plantation projects aimed at rehabilitation and restoration of those critical forests or lands, however, were hardly considered as successful. Many reasons has been stated, such as the conditions of forest or land, which are so marginal and difficult to manage; the climatic condition, which is often unsuitable; the social condition of local community surrounding the forest or land, who is not conducive; or the amount of fund, which is often less and not well managed.

The condition of Tahura Senami is not different. Effort to restore and rehabilitate degraded primary forest and secondary forest, as well as degraded land at Tahura Senami has been done, without significant result. In order to get satisfactory result such effort clearly needs complete pre- assessment of both the biophysical condition of Tahura Senami and land, as well as the social aspect of local community.

The biophysical environment plays important role in tree growth. Although year-round temperature, solar radiation and humidity at Tahura Senami are conducive to rapid growth of planted trees, often limiting factor is soil fertility. Principal soil related constraints to sustainable productivity include water imbalance, nutrient imbalance, low effective rooting depth due to unfavorable soil physical and chemical properties, and high salt concentration in the root zone. Predominant soils of the tropics have low inherent fertility, have severe nutritional constraint and prone to degradation (Lal, 1997). Improper land-use and soil mismanagement can cause further fertility depletion and structural degradation. Therefore, a systematic evaluation of soil properties and processes is needed to develop a sustainable soil and water management to ensure successful plantation establishment.

Objectives

The objectives of this paper is to evaluate the physical and chemical properties of soil at the degraded primary forest and secondary forest, as well as degraded land of Taman Hutan Raya Sultan Thaha Syaefuddin or Tahura Senami, in order to develop a science-based soil management as part of the silvicultural practice. The information will ensure the best result of plant growth in the restoration and rehabilitation process, also agroforestry establishment in the area.

Methodology

Soil Sampling

At each land-use type, i.e. degraded primary forest, secondary forest and degraded forest land, which are subject to restoration, rehabilitation, and agroforestry establishment, either transect or plot were made both for vegetation analysis and soil sampling. For soil fertility investigation, sampling is limited to the 40 cm upper layer, which is constantly change as it receives litter, nutrients extracted by roots from deep layers and thus reflects the fertility of the soil (Wilde *et al*, 1979).

At restoration site of Senami village, totally 7 transects (size 20 x 500 m) were made. From each transect soil samples were taken, i.e. one sample for physical properties analysis, and one sample for chemical analysis. At agroforestry and rehabilitation sites of Senami, a totally 5 plots, size 20 x 20 m, were established representing all types of land-use present. Soil samples were collected from inside each plot, and vary in number of samples for each land-use: totally 4 samples at old rubber plantation, 6 samples for deserted land, 2 samples for bushy grassland, and 2 samples for rehabilitation site.

At rehabilitation and agroforestry sites of Bungku village, a totally 5 plots, size 20 x 20m, were established representing all types of land-use present. Number of soil samples collected for each land-use type is as follows: 4 samples at rehabilitation sites, 2 samples for old rubber plantation, and 4 samples for bushy grassland.

All samples were taken at randomly selected points, at 0 – 20 cm and 20 – 40 cm soil depth.

Laboratory analysis

Laboratory analysis of soil samples consisted of 2 parts, i.e. physical properties and chemical properties. Including in physical properties of soil, are bulk density, soil porosity, soil permeability to water, and soil texture. For analysis of physical properties only 1 (one) sample was used from each transect or plot made in the sampling. Result from several transects or plots, made within one land-use of one location, were then averaged.

Chemical properties of soil include: soil pH, cation exchange capacity, degree of base saturation, carbon-organic content, total nitrogen content, available phosphorus, exchangeable potassium, calcium and magnesium. For analysis of chemical properties 1 – 3 samples from each transect were composite. Result from several transects or plots within one land-use of one location were then averaged. Method used in each analysis as follows:

1. Determination of bulk density

   Soil sample in the core cylinder was removed, and dried to constant weight in the oven at 110^{o}C. The sample was then weighed. The weight of the soil sample divided by its volume gives the bulk density.

2. Determination of the porosity of soil

   Porosity is expressed in percent by volume, and calculated from the value of bulk density (D) and specific gravity (S) of soil. Soil specific gravity is determined by the use of a pycnometer, and calculated as the ratio of the weight of any volume of soil material to the weight of an equal volume of water.

3. Determination of permeability of soil to water

   Permeability is determined by recording the period of water infiltration through a column of soil sample.

4. Determination of soil texture

   Percentage of sand, silt and clay in the soil sample were determined by standard Bouyoucos hydrometer method.

5. Determination of carbon content in the soil organic matter

   The carbon content in soil organic matter was determined by Walkley-Black method. This method basically is a colorimetric determination using titration procedure.

6. Determination of total nitrogen

   Total nitrogen in the soil was determined by standard Kjeldahl method.

7. Determination of soil pH

   The value of pH in the soil solution was determined by pH-meter.

8. Determination of available phosphorus (P)

   Available P was determined using standard Bray method, which utilized NH_4F to extract P from the soil.

9. Determination of exchangeable potassium (K), calcium (Ca) and magnesium (Mg)

   Accurate determination of exchangeable K, Ca and Mg was accomplished by atomic absorption spectrophotometry. Extracting solution for spectrometric determination used ammonium acetate or a mixture of ammonium acetate and magnesium acetate. A standard curve was used to convert the galvanometer readings to ppm of K, Ca and Mg.

10. Determination of cation exchange capacity

    Cation exchange capacity was calculated from the amount of extracted aluminum from the soil. Extraction was done using ammonium acetate. Determination of aluminum content was done by atomic absorption spectrophotometry.

11. Determination of degree of base saturation

    Degree of base saturation was expressed as a percentage of total exchangeable bases to the exchange capacity. Total exchangeable bases was calculated by adding the value of each exchangeable base, i.e. K, Ca, Mg, Al and H, which was determined previously. All determinations were made using atomic absorption spectrophotometry.

Results and Discussion

Results presented in all tables are average value of samples from one land-use type of one location.

Physical Characteristics

In general field conditions of Tahura Senamis are flat to undulate within an altitude range of 10 – 100 m above seal level. Dinas Kehutanan (2006) reports that dominant soils are red yellow podzolic (70%) followed by Alluvial (18%), Granosol (3.24%) and other soils (8.58%).

Table 1. Bulk density, porosity and permeability of soil at restoration, rehabilitation and agroforestry sites, within 0-20 cm and 20-40 cm soil depths

Location/Land Type	Bulk density (g/cm^3)		Porosity (%)		Permeability (cm/hr)	
	0-20	20-40	0-20	20-40	0-20	20-40
Senami						
Restoration	1.07	1.25	59.39	52.64	13.02	5.44
Rehabilitation	1.07	1.24	59.50	53.14	8.54	4.51
Agroforestry:						
RP	1.21	1.42	54.22	46.22	6.97	2.11
DL	1.19	1.22	55.16	53.91	9.45	3.81
BG	1.02	1.17	61.68	55.75	7.15	3.03
Bungku						
Rehabilitation	0.91	1.35	65.78	49.18	13.18	6.82
Agroforestry:						
RB	1.12	1.13	57.55	57.94	8.64	2.87
BG	1.11	1.16	57.83	56.03	9.96	2.97

Notes :
RB : Old rubber plantation
DL : Deserted lands
BG : Bushy Grassland

Table 1 and 2 show the physical properties of soil at restoration, rehabilitation and agroforestry sites. The soil at Tahura Senami has average bulk density, normal porosity and permeability to water. From the percentage of silt and clay, the soil can be classified as sandy loam to light loam (Wilde *et al*, 1979).

Table 2. Soil texture at restoration, rehabilitation and agroforestry sites, within 0-20 cm and 20-40 cm soil depths

Location/Land Type	Sand (%)		Silt (%)		Clay (%)	
	0-20	20-40	0-20	20-40	0-20	20-40
Senami						
Restoration	57.35	57.59	16.02	15.29	26.62	27.11
Rehabilitation	53.35	47.72	16.17	14.90	30.48	37.78
Agroforestry:						
RP	62.83	57.02	17.88	12.68	19.28	30.29
DL	26.92	25.04	35.06	32.61	38.02	42.35
BG	43.33	38.41	33.93	38.53	22.74	23.06
Bungku						
Rehabilitation	46.37	40.61	28.21	39.14	25.42	20.25
Agroforestry:						
RB	34.86	33.56	43.18	35.94	21.96	30.50
BG	36.17	30.78	42.23	38.01	21.59	31.20

This type of soil is expected as having sufficient water-holding capacity and nutrients, which permits the growth of several forest tree species. The red-yellow pozolic, which dominates the soil at the project sites, is often classified into either Oxisols or Ultisols. According to Lal (1997) Oxisols and Ultisols have generally favorable soil physical characteristics.

Chemical Characteristics

Chemical characteristics of soil at project sites can be seen at Table 3, 4 and 5. Typical to red-yellow podzolic or Oxisols and Ultisols soil order, the soils have low pH value, ranging from 4.20 – 5.25, which means the soils are highly acidic. According to Lal (1997) the soils may contain toxic Al and Mn, are low in available P, and are low in major plant nutrients (i.e. N, P, K, Ca and Mg).

Content of C-organic and total N in the soil can show the productivity of the soil. A productive soil should at least contain 0.1 % of total N, and normal C/N ratio of soil is approaching 10 (Wilde *et al*, 1979).

Table 3. Soil pH and percentage of C and N at restoration, rehabilitation and agroforestry sites, within 0-20 cm and 20-40 cm soil depths

Location/Land Type	pH		C-organic (%)		N-total (%)	
	0-20	20-40	0-20	20-40	0-20	20-40
Senami						
Restoration	4.24	4.35	1.72	0.71	0.13	0.07
Rehabilitation	4.70	4.40	3.36	0.96	0.26	0.10
Agroforestry:						
RP	4.70	4.65	1.49	0.60	0.12	0.06
DL	4.90	4.90	1.39	0.81	0.11	0.08
BG	5.10	4.80	1.89	0.53	0.13	0.05
Bungku						
Rehabilitation	4.50	4.20	2.02	0.59	0.19	0.06
Agroforestry:						
RB	4.30	4.60	1.70	0.57	0.15	0.06
BG	5.25	4.70	2.03	0.65	0.17	0.07

Results of analysis on the extent of macro elements present in the soil can be viewed at Table 4 and 5. Phosphorus, calcium, magnesium and potassium are nutrient elements essentials for the growth of plants as well as microorganisms. Although in general the soils' physical properties have favorable nutrients holding ability, the low pH of the soils may cause unavailability of those nutrients to plants.

The ability of mineral and organic colloids of soil to retain and exchange ions commonly found in soils, is termed the "exchange capacity" of soils. The colloidal fraction or "exchange material" acts as a storehouse, in which nutrient ions are preserved in a form available to plants but not readily removable by leaching. Because of this, the magnitude of the exchange capacity determines to a large degree the level of soil fertility (Wilde *et al*, 1979). On soil with low exchange capacity, e.g. 5 me. per 100 g, it would be unwise to apply high dose of fertilizers, because the soil would not be able to contains the nutrients, and considerable portion of nutrients in the fertilizers would be washed away by run off, becoming unavailable to plants.

Table 4. Soil content of P, Ca and Mg ions at restoration, rehabilitation and agroforestry sites, within 0-20 cm and 20-40 cm soil depths

Location/Land Type	P (ppm)		Ca (me/100 g)		Mg (me/100g)	
	0-20	20-40	0-20	20-40	0-20	20-40
Senami						
Restoration	9.68	11.04	0.70	0.64	0.22	0.17
Rehabilitation	8.20	11.40	1.30	0.63	0.16	0.16
Agroforestry:						
RP	9.30	11.65	0.61	0.63	0.18	0.19
DL	6.40	10.90	0.60	0.60	0.21	0.20
BG	7.70	6.40	0.98	0.88	0.40	0.46
Bungku						
Rehabilitation	9.10	7.10	0.72	0.58	0.18	0.20
Agroforestry:						
RB	14.30	9.60	0.80	0.56	0.22	0.16
BG	8.50	8.40	2.48	0.79	0.56	0.43

Meanwhile total content of bases and degree of base saturation shows to what extent the exchange materials present in the soil. As shown in Table 5, the soils of Tahura Senami have low amount of bases or essential nutrients for plant growth.

Table 5. Content of K, cation exchange capacity and base saturation of soil at restoration, rehabilitation and agroforestry sites, within 0-20 cm and 20-40 cm soil depths

Location/Land Type	K (me/100g)		CEC (me/100 g)		BS (%)	
	0-20	20-40	0-20	20-40	0-20	20-40
Senami						
Restoration	0.07	0.04	8.36	6.95	14.93	13.96
Rehabilitation	0.05	0.04	10.69	6.78	14.87	13.42
Agroforestry:						
RP	0.07	0.05	7.80	6.16	17.46	12.59
DL	0.10	0.08	13.56	10.28	9.53	7.60
BG	0.30	0.16	8.43	6.37	25.43	22.30
Bungku						
Rehabilitation	0.04	0.04	12.74	9.86	9.13	7.85
Agroforestry:						
RB	0.05	0.08	8.63	8.22	13.56	10.95
BG	0.23	0.18	11.71	8.32	28.99	18.54

The soil at the project sites, which is belonged to Ultisols or Oxisols, is best kept under primary forest cover. During deforestation, a significant amount of bases is removed from the site in harvested biomass. The removal or retention of biomass will affect the balance of bases on the site accordingly. Meanwhile the removal of vegetation may change the microclimate and hydrological cycle too, resulting in increased mineralization of organic matter and accelerated soil erosion and leaching, which can cause depletion of bases and nutrients, and increase soil acidity. Therefore, intervention is needed when such soil is used for plantation, either for agriculture or forestry. The intervention includes improvement of soil pH by adding lime, conservative field preparation, and fertilizers application.

Conclusions

Results of soil analysis shows that soils at Tahura Senami can be classified as sandy loam to light loam, which have favorable physical properties. Some favorable properties are well porosity and permeability, which are important for plant root growth. The chemical properties of Senami soils, which is mainly belonged to red-yellow podzolic or Ultisols and Oxisols, however, pose many constraints for plant growth. Main limiting factors for plant growth are low pH and low available essential nutrients, i.e. P, K, Ca and Mg. Although soil exchange capacity is moderate, degree of base saturation is relatively low. Plantation establishment, such as restoration, and rehabilitation activities, or agroforestry, would require intervention into soil fertility to achieve well grown plants. Intervention can be done in the form of improvement of soil pH by adding lime, conservative field preparation, and fertilizers application.

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