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Effect of Soil Damage on Carrying Capacity of Biomass Production: A Lesson from Tanjung Selor District – Tanjung Redeb, Indonesia

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Abstract Currently, land use is considered intensive for various purposes that affect the soil as the main series of land and the environment. The other side of the soil in Kalimantan is naturally formed from material that is poor in nutrients so it is not fertile and acidic. This study attempted to evaluate the status of soil damage to the carrying capacity for biomass production in Tanjung Selor District. The overlay analysis of land slope, rainfall, soil type and land cover in the form of a map produces indicative areas of low, medium and high damage. High damage indicative areas were selected for verification, observation and soil sampling to obtain soil damage parameter data, carried out in March 2020. Analysis of the relative frequency score of the damaged parameters aims to determine the status of carrying capacity and soil damage. The results of the study based on 10 soil damage parameters obtained a score of 6 with the status of lightly damaged soil damage, the main factor being soil acidity (R.I-a) with a high carrying capacity of 1,684 ha. The acidity factor with a pH of <4.5 (very acidic) has the most effect, 80% is damaged, but is relatively easy to repair. Efforts to improve cultivated plants are stressed by soil acidity by using soil amendments to raise the pH above the minimum range that is more suitable to increase biomass production and carrying capacity, namely agricultural lime and compost followed by N, P and K fertilization as needed.

Keywords Land Use, Soil Damage Status, Biomass Production, Carrying Capacity

1. Introduction

Land use for various activities and purposes is increasing and even intensive, so that it affects the quantity and quality of the land component, namely the lithosphere. Lithosphere is part of the outer shell of the earth consisting of rocks and soil that supports life on it, among others, to produce biomass. As a component of land and the environment, the use of land that is more diverse and wider without considering the carrying capacity can cause soil damage which reduces the production of plant biomass on it. In the context of the environment, carrying capacity is articulated as a harmonization that supports the life of living things fundamentally for the long term, especially humans [1].

Soils in Kalimantan are formed from repetitive, nutrient-poor residual parent materials such as sandstone. Nutrients that come out are not replaced or replaced but the amount and type are not balanced and for a long time, so that the quality of the soil is reduced or damaged which reduces its carrying capacity for biomass production [2-3]. Another factor is the high rainfall and lasts most of the year with a long period of time and this indicates that alkaline metal nutrient loads are leached to the lower layers and some are carried away by groundwater into water bodies with the consequence that the soil is relatively poor in nutrients and acidic.

As for the motivation and objectivity of this article to understand the status of soil damage to the carrying capacity for biomass production in Tanjung Selor District, to the author's knowledge, this paper is one of the premises that using more holistic procedures and techniques than other publications. A study that relates soil damage to carrying capacity is based on indicative soil damage parameters. Production of green plant biomass in the form of fruit, tubers, leaves, shoots, stems, skins, flowers, oil as the main food chain on land and life support material. High biomass production can be achieved if the soil of the growing medium is good, otherwise if the soil is damaged. This may be of interest to stakeholders, particularly policy makers.

2. Materials and Methods

2.1. List of Equipments

Operationally, the main research equipment or item consists of soil samples and thematic maps. The maps in question are the 2012–2032 Bulungan Regency Spatial Plan [4], soil type maps [5], Indonesian topographic maps 1918-42 and 1918-44 [6], Digital Elevation Model (DEM) maps [7], rainfall [8] and land cover map [9] categorization refers to Indonesian National Standard (SNI) No.: 7645-1:2014 [10]. All them are digital-based to support mapping mechanisms and operations. Soil sampling is focused on strategic locations, where observations of high soil damage potential refer to thematic maps accurately. Field activities are equipped with GPS, soil drill, double ring, clinometer, plastic bag and machete. Laboratory equipment and chemicals for soil testing. Then, soil samples identified in the laboratory include: soil biology (bacteria and fungi), chemical properties (pH, DHL, and Redox), and physical properties (fraction composition, specific gravity, and total pores) at the Soil Laboratory at the Faculty of Agriculture – Universitas Mulawarman.

2.2. Indicators

The concentration of areas that become effective work areas is cultivation areas [4] which so far have become prospects for expansion of biomass production, such as horticultural cultivation areas, agricultural and plantation areas, and permanent production and limited production forest areas. Meanwhile, other cultivation areas such as settlements, protected areas, fisheries, and others are not included in the effective areas [11-14].

2.3. Indicative Land Damage

The requirements for measuring indicative damage are based on 4 parameters that are weighted based on their strong influence on soil damage, i.e. slope (%) and rainfall ($mm.th^{-1}$) weight 3, soil type (*Ordo*) and land cover weight 2, total weight 10 [15-17]. Each vital parameter is rated according to its potential damage. The ratings for each parameter are: Slope 1 (1-8%), 2 (9-15%), 3 (16-25%), 4 (26-40%), and 5 (>40%). rainfall 5 (> 4000), 4 (3000-4000), 3 (2000-3000), 2 (1000-2000), and 1 (<1000). Soil 1 (*Vertisols Aquic moisture regime*), 2 (*Oxisols*), 3 (*Mollisols*, *Ultisols*), 4 (*Inceptisols*, *Entisols*, *Histosols*), and 5 (*Andisols*, *Spodosols*). Land cover related to crop coefficient includes 1–Natural forest, rice fields, pure fertile alang-alang; 2–Mixed gardens, shrubs, meadows; 3–Production forests, cultivation; 4–Perennials; and 5–Open land [18]. This land cover will be equivalent to the land cover of SNI: 7645-1:2014 found at the activity site [10]. Each weight multiplied by the rating yields a specific score [19-23].

2.4. Map Overlay

The next step is the treatment of overlapping operations with ArcGis version 10.2 on slope maps, rainfall maps, soil types maps and land cover maps [24-25]. Sudaryatno [26], Hernando & Romana [27], and Roesch *et al*. [28] popularized the most important parts obtaining total scores (smallest 10) and (largest 50). The entire map area is only in the effective working area. It should be noted that the total score is classified according to the assumption of indicative soil damage potential into 5 classes (*Table 1*). These results provide a spatial sign of potential soil damage as a guide for field verification.

Table 1. Indicative soil damage potential

Groups	Score
“Very high”	≤45–50
“High”	≤35–44
“Moderate”	≤25–34
“Low”	≤15–24
“Very low”	<15

Source: adopted from Siahaan [29]

2.5. Field Verification

Furthermore, field verification only focuses on locations of high indicative soil damage potential to prove the truth of the potential damage [30]. When in the field, the independent system soil observations at 10 representative sites of the dimensions of solum thickness, surface rock, degree of water release, and taking soil samples at a depth of 0–20 cm for laboratory review [31-33].

2.6. Categorization of Land Damage Status

Finally, compile the status of soil damage using the relative frequency scoring method with the provisions of the comparison of the number of soil samples based on the parameters of the laboratory analysis results classified as damaged (%) to all soil samples.

Other parameters observed directly in the field were classified as damaged (%) against all observations of the same parameters in the field (see *Table 2*). The types of parameters and their assessments refer to *Table 4*, the parameters are declared damaged if they are outside the threshold. The maximum accumulated score is 40 if all or 10 parameters (*Table 4*) are damaged, then divided into 5 classes (*Table 3*).

Each parameter that has been scored is then added up, from that number the soil damage status (dry land) is categorized as represented by *Table 3*.

Table 4 interprets the criteria for dry land soil damage referring to 10 parameters and each with a threshold. Each field observation sample and the observed soil sample have 10 parameters, the results are compared to determine the parameter that is damaged if the value is outside the threshold.

Table 2. Relative frequency ground damage score

Frequency (%)	Score	Measures	Carrying capacity
0 – 11	0	“Not damaged”	“Very high”
11 – 25	1	“Slightly damaged”	“High”
26 – 50	2	“Medium”	“Moderate”
51 – 75	3	“Heavily damaged”	“Low”
76 – 100	4	“Very heavily damaged”	“Very low”

Source: Darma *et al.* [34]

Table 3. Relationship of accumulated score to soil damage

Symbol	Accumulated score	Status	Carrying capacity
R.IV	35–40	“Very heavily damaged”	“Very low”
R.III	25–34	“Heavily damaged”	“Low”
R.II	15–24	“Medium”	“Moderate”
R.I	1–14	“Slightly damaged”	“High”
N	0	“Not damaged”	“Very high”

Source: compilation from Syahidah [35]

Table 4. Dry land soil damage criteria

Parameters	Symbol	Levels
pH (H2O) --> 1:2.5	a	<4.5 or >8.5
Surface rock	b	> 40%
Filling weight	d	> 1.4 $g.cm^{-3}$
Electrical conductivity/DHL	e	> 4.0 $mS.cm^{-1}$
Composition of colloidal clay and sand fraction	f	<18% clay colloid or >80% tick quartz sand
Number of microbes	m	$<10^2$ $cfu.g^{-1}$soil
Degree of water pass	p	<0.7 $cm.hour^{-1}$ or >8 $cm.hour^{-1}$
Redox	r	<200 mV
Solum thickness	s	<20 cm
Solum thickness	s	<20 cm

Source: Qurrahman *et al*. [36] dan Sumarno *et al.* [37]

3. Results and Discussion

3.1. Parameter of Scores Each

After reviewing the slope class, there were scores of 3 (1-8%), 6 (9-15%), 9 (16-25%), 12 (26-40%), rainfall scores 9 (2000-3000). Soil type with a score of 6 (*Ultisols* and *Alfisols*), and 8 (*Inceptisols* and *Entisols*). Land cover from SNI: 7645-1:2014 [10] found 10 equalized classes, where a score of 2 (natural forest, rice fields, pure fertile reeds) was equal to dry land forest, ponds, secondary swamp forest swamp scrub, and secondary mangrove forest. Then, a score of 4 (mixed gardens, shrubs, grasslands) is equal to plantations, a score of 6 (production forest, cultivation), is equal to dryland agriculture, shrubs/shrubs, a score of 8 (seasonal crops) is equal to dryland annual crops, and a score of 10 for open ground.

3.2. Exploration with Overlays

The effective work area in Tanjung Selor Regency supports the designation of a cultivation area with a 39,800 ha. The overlay of the slope map, rainfall map, soil type map, and land cover map obtained a total score between 20–42 which indicates that the potential for soil damage is indicative of low, medium, to high (see *Table 5*).

High indicative soil damage potential is designated as a location for field verification for evaluation and proof of the actual land damage status. The verification point was chosen with consideration of the ease of accessibility and representativeness of the location.

Table 5. Findings on soil damage are indicative

Potential damage	Area (ha)
Low	7,735
Moderate	30,381
High	1,684
Total	39,800

Source: elaboration of Authors

3.3. Overview Attributes

The results of the verification which focused on high indicative damage areas were carried out in early March 2020, observations were made of 10 locations as representatives, it was found that the soil solum depth for all sample points was >60 cm, slopes 15%–40%, there was a small part of slopes >40%, but only to the extent of inclusion. Interestingly, there are surface rocks with a size of about 2 mm–7.5 cm, but the determination is between 2 mm–1 cm, thus it is classified as gravel. Gravel on the surface and cross section of the soil, to a depth of >40cm with a general distribution of <10%, but two locations ± 45%. Soil permeability is between 0.55–10.40cm.hour^{-1}. At each observation location, soil samples were taken for laboratory analysis.

3.4. Soil Damage Assessment

Table 6 summarizes the field verification study and the soil analysis. The soil damage parameters are outside the threshold and the parameters are within the threshold. The data collected refers to observations and selection in the field, laboratory studies and analysis of soil damage status, it is concluded that the accumulated score is 6.

Table 6. Soil damage assessment based on relative frequency score

Parameters (symbol)	Components		Soil observations and samples			
	Value	Unit	I	II	III	IV
Solum thickness(s)	< 20	cm	>90	60–90	60–90	>90
Surface rock (b)	> 40	%	<10	45*	<10	<10
Composition of sand fraction (f)	< 18	% clay	36.7	40.3	12.57*	42.26
	> 80	% sand	48.7	30.8	73.3	16.86
Filling weight (d)	>1.4	g.cm^{-3}	1.30	1.42*	1.32	1.34
Total porosity (v)	< 30; >70	%	47	43	53.12	42.3
Degree of water release (p)	< 0.7; >8	cm.hour^{-1}	0.71	0.55*	7.15	1.02
pH (H2O) --> 1:2.5	< 4.5; >8,5	-	4.4*	4.3*	4.10*	4.2*
Electrical conductivity (e)	> 4	mS.cm^{-1}	1.87	1.34	2.26	1.97
Redox(r)	< 200	mV	247	200	235	241
Number of microbes (m)	<10^2	cfu.g^{-1}soil	2.2 x 10^4	1.9 x 10^4	2.1 x 10^4	2.1 x 10^4

Table 6. Continued

Soil observations and samples						Σ damaged	Relative frequency of damaged soil (%)	Score
V	VI	VII	VIII	IX	X			
>90	>90	>90	>90	>90	60-90	0	0/10 x 100 = 0	0
>10	<10	<10	<10	<10	45*	2	2/10 x 100 = 20	**1**
29.9	23.1	32	61.2	53.7	17.2*	2	2/10 x 100 = 20	**1**
52.8	55.9	45.26	39	46.3	72.9	0	0/10 x 100 = 0	0
1.28	1.22	1.28	1.28	1.3	1.26	1	1/10 x 100 = 10	0
56.41	52.57	53.66	50.08	40.43	56.32	0	0/10 x 100 = 0	0
3.06	10.40	3.36	6.32	4.99	7.64	1	1/10 x 100 = 10	0
4.30*	5.84	4.81	4.13*	4.42*	4.33*	8	8/10 x 100 = 80	**4**
3.35	4.05*	3.05	2.83	3.47	1.95	1	0/10 x 100 = 10	0
213	225	231	275	232	284	0	0/10 x 100 = 0	0
1.8 x 10^4	1.7 x 10^4	2.2 x 10^4	1.8 x 10^4	2.2 x 10^4	1.9 x 10^4	0	0/10 x 100 = 0	0
Accumulated score								**6**

Source: elaboration of Authors. *Remark:* *) Beyond critical threshold

Table 6 also explains the accumulated score of soil damage status, which is lightly damaged (R.I) or high carrying capacity with an area of 5,604 ha, originally indicated with high damage potential. The factors causing the soil damage status that affect the status of the soil consist of three main classifications, namely surface rock, clay fraction composition (f), and pH or soil acidity. From this aspect, the pH factor is the largest (80%) outside the threshold, the surface rocks, and the composition of the clay fraction is only 20%. But, the density and degree of water release are only 10% or one point of observation. The dominant soil acidity is below the threshold (<4.5) with a very acidic status.

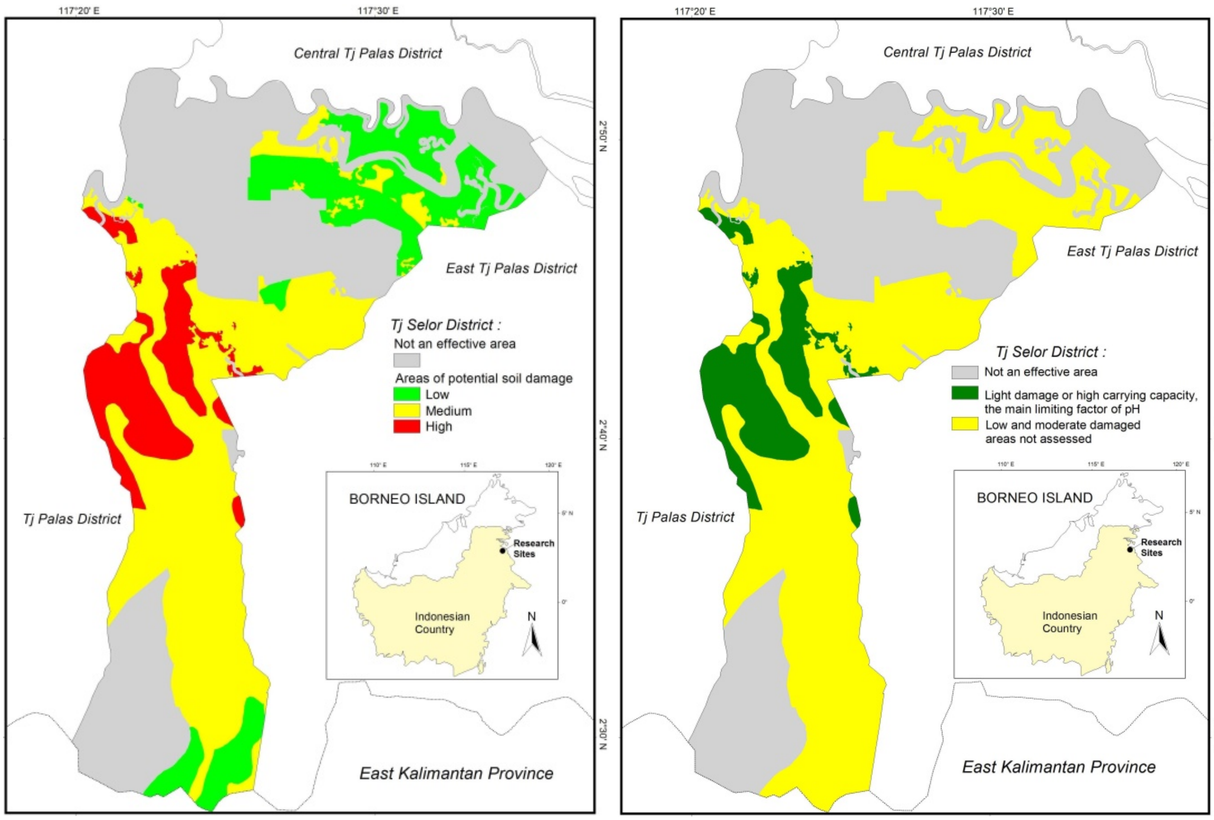
The main soil group (*Ordo*) in the overall study area that is dominant is *Ultisols* or *Podsolik* with an area of 29,329 ha or 73.70% in the effective area [38-39]. Soil acidity of Ultisols in Kalimantan with a pH of 4.22-4.77 is classified as very acidic [40-42]. The damage status of lightly damaged soil which was originally indicated as having high damage potential can give the same picture that the indication of low and moderate damage is the main factor is pH, especially those found in the same soil type (*Ultisols*) so that it is classified as lightly damaged.

The status of soil damage with the main limiting pH is very acidic (R.I-a), but the soil still functions well as a natural medium for natural vegetation to grow. Yet, land use for cultivation that produces biomass must be regulated, and maintained so that biomass production remains good [43]. The existing vegetation has adapted to the soil conditions where it grows in a long period [44]. This vegetation can produce biomass in the form of stems, leaves, flowers, fruits, tubers, sap, bark, roots and oils that support animal life and human dependence in the vicinity.

Table 7. Variety of cultivated plants and their tolerance to minimum soil pH

Plant type	Minimum pH
Foods:	
- Local/upland rice fields	4[1]) – <5[3])
- Cassava	4[1]) – <4.8[3])
- Sweet potatoes	4[1]) – <4.8[3])
- Corn	4[1]) – <5[3])
- Taro	4[1]) – <5[3])
Plantations:	
- Coconut	4[1]) – <4.83)
- Palm oil	3.5[2]) – <4.2[3])
- Rubber	3.5[2]) – <4[3])
- Cocoa	4[1]) – <5.5[3])
- Robusta coffee	4[1]) – <5.3[3])
Vegetables:	
- Beans	4[1]) – <5[3])
- Eggplant	4[1]) – <4.8[3])
- Cucumber	4[1]) – <4.8[3])
- Chilli	4[1]) – <5[3])
- Petai	4[1]) – <5[3])
Fruits:	
- Durian	4[1]) – <5[3])
- Banana	4[1]) – <5.2[3])
- Papaya	4[1]) – <5.5[3])
- Cempedak/Nangka	4[1]) – <4.5[3])
- Rambutan	4[1]) – <4.5[3])

Notes: [1)] Rounding off the lowest soil pH at the activity site, [2)] Observations of the authors at several locations in North Kalimantan, and [3)] adopted from Ritung *et al*. [45]



(a) Indicative soil damage *(b) Potential carrying capacity*

Source: elaboration of Authors

Figure 1. Map of study stage

A variety of vegetation are needed by humans, such as food-producing plants, horticulture, secondary crops, vegetables, and plantation crops, most of which are not native plants. This is caused by cultivation activities that allow the process of adaptation to their environment. Although growing, these plants require certain requirements to provide good results to the greatest. Observing *Table 7*, plant varieties can produce and grow well in the least soil pH interval, although not optimally [46-47]. Parameters of very acidic soil damage have an explicit impact on the carrying capacity of production yields for a case study of several cultivated plants. Soil pH factors, which are very acidic (<4.5) with dominant (80%) in the study area, must be considered for the suitability of the variety of plants that will be and have been developed (see *Figure 1*).

The act of providing soil amendments is to increase soil pH, including within a range that is more suitable for the type of plant and compost [48-51]. In terms of soil amendments, agricultural lime is very suitable for reducing soil acidity or increasing soil pH in encouraging better alignment of plant guidance ranges (above the minimum). Compost is also applicable to increase soil fertility (physical, chemical, and biological) and maintain soil pH stability. Also to soil improvement, extra fertilizer containing N, P and K elements is also good and important to give to plants to increase nutrient availability so that optimal biomass production implies increasing carrying capacity [52]. Very acidic soils are followed by very low to low macronutrient deficiencies [53-55].

Other studies examining the effect of biomass production on soil degradation are discussed. Case study in the Idaho forest in Washington, watershed degradation leads to expansive human use of biomass [56]. Uncontrolled biomass production practices in the eastern part of Natuna Regency, for example, degraded soil quality and function are triggered by development routines [57]. There is similar literature, but different research outputs are also shown by Frasetya *et al*. [58]. The use of land for production forests and explorative agriculture has an impact on land degradation in Subang in West Java (Indonesia). Collectively, Pimentel & Burgess [59] argue that world food production is currently the most concrete threat with implications for soil erosion on agricultural land. Humanity will experience hunger as a result of the food security crisis. Yang *et al*. [60] confirmed that drastic environmental changes actually disrupt the stability of plant biomass productivity. By ignoring soil biodiversity, temporal biomass production cannot respond to plant functional groups. Eisenhauer *et* *al*. [61] found that there is a positive correlation between plant biomass production and sustainable decomposer diversity.

4. Conclusions

The orientation of this research is to explore the relationship between soil damage and the carrying capacity of biomass production from Tanjung Selor District in Bulungan Regency (North Kalimantan Province). Initial analysis of the 4 main parameters of the output indicated high soil damage as a reference for field verification. However, further analysis shows that the soil damage status is lightly damaged (R.I-a) with the main limiting factor being very acidic soil acidity. Thus, the carrying capacity of the soil for biomass production is still high. For cultivated plants, it is necessary to provide soil amendments (captan and compost) to reduce the main limiting effect to increase production capacity massively. Additionally, N, P and K fertilizers need to be given to increase soil fertility so that biomass production and carrying capacity are optimal.

Theoretical contributions and practical implications are developed to assist practitioners and researchers in considering the carrying capacity of biomass production and soil degradation. The limitations and directions of future studies are discussed for a more exclusive generalization of these findings and new research flows in the field.

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