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Analysis of Land Suitability for Arabica Coffee in Toba Regency, North Sumatra, Indonesia

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Abstract. Coffee is a mainstay plantation commodity in Toba Regency which is managed independently by the community where the land around the Lake Toba area is one of the potential lands in Toba Regency for developing Arabica coffee commodities because geographically Toba Regency is located at an altitude of 900 meters to 2,200 meters above sea level and directly borders Lake Toba. The strong roots of coffee plants make this plant one of the mainstays in preserving forests, restoring critical land, preventing erosion and flooding during the rainy season. The aim of this research is to analyze the land suitability of Arabica coffee plantations in Toba Regency. The method used to analyses the land suitability by using the matching method which was carried out by matching land characteristics with parameters/ criteria for plants based on Land Map Unit (LMU). The research results show that the area of Toba Regency based on the Geographic Information System (GIS) is 207,518.31 ha. Very suitable (S1) land suitability for Arabica Coffee Plants covering an area of 67,844.68 ha (32.69%), an area of 132,030.09 ha (63.62%) has S2 suitability class and an area of 7,643.54 ha (3.68%) has marginal suitability (S3). The potential land suitability class for coffee plants in Toba Regency becomes very suitable (S1) covering an area of 67,844.68 ha or 32.69%, moderate suitable class (S2) with temperature limitation covering an area of 132,030.09 ha (63.62%) and marginal suitability (S3 with temperature limitation) covering an area of 7,643.54 ha or 3.68%. Nutrient deficiencies were corrected by adding phosphorus (P) fertilizer of 4.19 kg P/ha or 9.31 kg SP36/ha or 11.63 kg TSP/ha. Nitrogen (N) fertilizer is 75 kg N/ha or the equivalent of 166,625 Kg Urea/ha. Potassium (K) fertilizer as much as 3 kg KCl/ha. Compost fertilizer is 10.56 tons of compost/ha.

Keywords: Arabica Coffee, Land Suitability, Geographic Information System (GIS).

1. Introduction

Toba Regency is one of seven regencies that surround Lake Toba, which is the largest lake in Indonesia. Toba Regency has an area of 2,021.80 km² (Ministry of Home Affairs, 2021) or 3.19% of the total area of Sumatra Utara Province (BPS Kabupaten Toba, 2021). Plantation crops in Toba Regency are generally businesses managed independently by the people, including Arabica coffee. Coffee plants are smallholder plantation crops with the largest planting area compared to other plantation crops, namely 3,558.83 Ha. Based on the physical description of the land on the Toba Regency land use map, it can be seen that the land potential in Toba Regency is still very large to be developed into productive land, especially for the agricultural, forestry, plantation, livestock, tourism, industrial, mining, etc. Because a lot of land in this Regency is unused, this land should be utilized according to its potential based on land suitability class analysis.

Land resources include all characteristics and processes as well as land phenomena that can be used to meet human needs. One important type of land use is the use of land resources in agricultural land utilization types to obtain agricultural and livestock products. (Hardjowigeno, 1985). Efforts to utilize agricultural land are essentially aimed at obtaining results from agricultural commodities. Land resource management activities in this case are basically an effort to adjust existing land conditions to the requirements for agricultural commodities (Sitorus, 1985). The potential of land resources in fact invites a lot of investment from outside the region to "work" on the land more intensively. In the end, this will result in the emergence of an increasingly large "gap" between the intensity of resource use and the characteristics of the resource. If this gap exceeds the carrying capacity of the resource, the rate of degradation will exceed the tolerance threshold. Meanwhile, farmers' strategies for struggling to maintain their livelihoods usually rely on three specific basic principles, namely: 1) To meet their basic needs, farmers manage their land resources with various crop, livestock, horticultural and forestry production activities, 2) Farmers avoid the risk of failure and disaster through development of indigenous methods in managing land, and 3) Technology that is easy, low input and small scale is preferred due to limited mastery of knowledge, technology and capital. Land has high potential if the land has several supporting components. These components or parameters include soil type, rock type, hydrological potential, slope slope and disaster vulnerability. The characteristics of potential land for agriculture are a high level of fertility, good physical properties and without erosion.

2. Methodology

Toba Regency is one of the Regencies in North Sumatera Province, Indonesia. Toba Regency has sixteen sub-districts, namely, Ajibata District, Balige District, Bonatua Lunasi District, Borbor District, Habinsaran District, Laguboti District, Lumban Julu District, Nassau District, Parmaksian District, Pintu Pohan Meranti District, Porsea District, Siantar Narumonda District, Sigumpar District, Silaen District, Tampahan District and Uluan District. The Toba Regency landuse map presented in Figure 1.

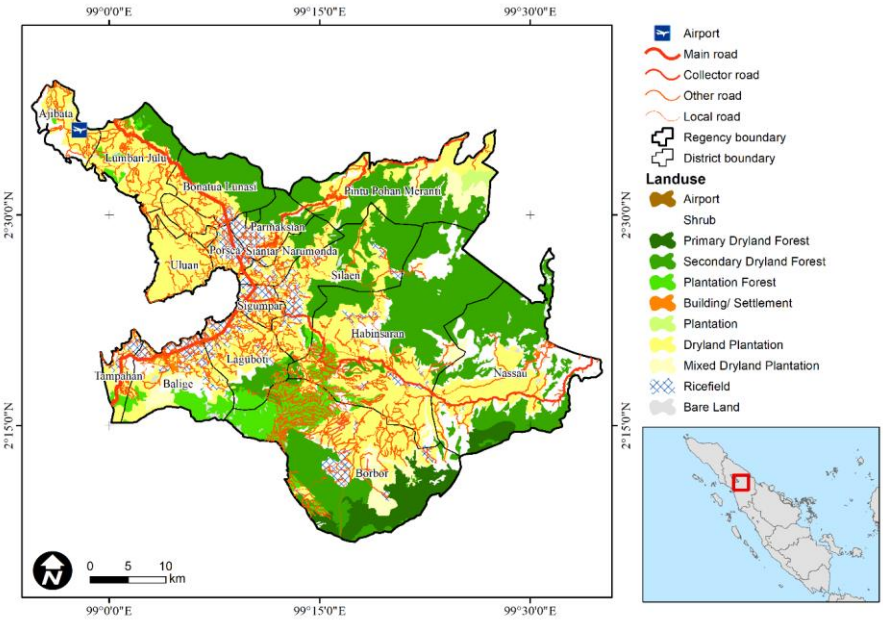

Figure 1. The Landuse Map of Toba Regency.

Landuse in Toba Regency consists of dry land agriculture, rice fields, primary dry land forests, plantations, mixed dry land agriculture, secondary dry land forests, settlements and shrubs. The slope of the land in each District is different, namely flat to wavy (0-8%), undulating (8-15%), hilly (15-25%), slightly steep (25-40%) and steep (> 40 %). Soil types in Toba Regency are andisol, entisol, inseptisol and Ultisol. Andisol soil has a loose soil structure, the consistency of loose soil. This causes Andisol land to have good potential for agricultural development. Entisol is a very young type of soil where the soil type has not yet formed a true horizon. Inseptisol is a type of young soil. This soil is usually found not far from volcanic areas, it can be thin surface soil that does not yet have a layer of soil. Ultisol is a soil with low organic matter, pH and nutrient content so it has low productivity. The dynamics of soil organic matter are influenced by changes in land use and soil management practices. The soil map presented in Figure 2.

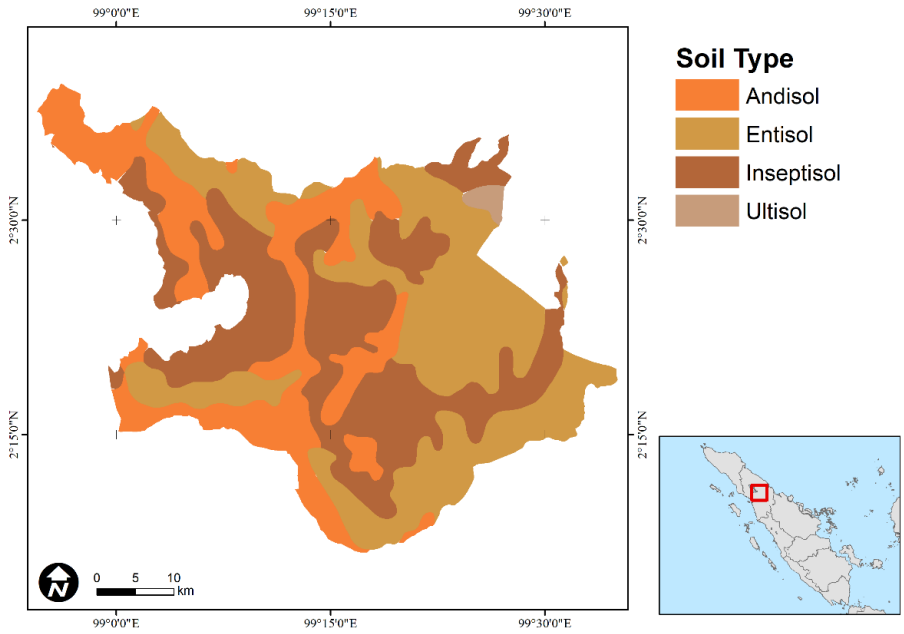

Figure 2. Soil Map of Toba Regency

The tool used in this research were GPS (Global Positioning System), soil drill, gembor, hoe, burlap, plastic, rubber, markers and name labels for marking, scales for weighing soil, and laboratory equipment for soil analysis. Research materials were administrative maps, Toba Regency land use maps, scale 1: 50,000, soil type maps, and topographic maps as well as chemicals for soil analysis purposes in the laboratory. The Land Map Unit (LMU) were resulted from intersection of Land Use Map and Soil Type Map, which resulted 25 LMU. The tools used in mapping land potentials were ArcView GIS software.

This research was conducted using a survey method consisting of three stages, namely

1. Preparation stage by procuring the required maps and creating a Land Map Unit (LMU).
2. Field activity stage by observing land characteristics at each LMU then by taking soil samples at each LMU
3. The data processing stage was carried out using the matching method, namely comparing the characteristics of the land at each SPL with the land suitability class criteria for Arabica coffee plants (*Coffea Arabica L.*) in Table 1. The land mapping unit is presented in Figure 3.

Table 1. Criteria of Land Suitabilty for Arabica Coffee

LMU	**Texture**	**pH H_2O**	**P_2O_5**	**N-tot**	**C Org**	**CEC**	**K_2O**	**BS**	**Suitability**	
			ppm	(%)	(%)	me /100g	me /100g	(%)	KA	KP
LMU 1	Sandy Clay Loam	**5,18 (M)**	16,03 (ST)	**0,13 (R)**	1,14 (R)	**7,71 (R)**	**0,16 (R)**	**16,76 (SR)**	S2	S1
LMU 2	Sandy Clay Loam	5,69 (AM)	15,13 (ST)	0,25 (S)	1,69 (R)	**8,77 (R)**	0,44 (S)	**42,29 (S)**	S3	S3
LMU 3	Sandy Loam	6,07	20,66	0,34	2,62	**11,01**	0,91	52,41	S2	S1

LMU	Texture	pH H_2O	P_2O_5	N-tot	C Org	CEC	K_2O	BS	Suitability	
			ppm	(%)	(%)	me /100g	me /100g	(%)	KA	KP
		(AM)	(ST)	(S)	(S)	**(R)**	(T)	(S)		
LMU 4	Sandy Clay Loam	5,45 (M)	**12,00 (T)**	0,22 (S)	1,87 (R)	**9,37 (R)**	0,42 (S)	**16,23 (SR)**	S2	S1
LMU 5	Sandy Loam	5,78 (AM)	**11,62 (T)**	0,22 (S)	1,67 (R)	**5,62 (R)**	**0,16 (R)**	**42,07 (S)**	S2	S1
LMU 6	Sandy Loam	5,47 (M)	**13,40 (T)**	0,21 (S)	1,49 (R)	**7,79 (R)**	**0,16 (R)**	**38,65 (R)**	S2	S1
LMU 7	Sandy Clay Loam	5,34 (M)	**12,51 (T)**	**0,20 (R)**	1,48 (R)	**8,75 (R)**	**0,28 (R)**	**28,64 (R)**	S2	S1
LMU 8	Sandy Loam	5,71 (AM)	16,02 (ST)	**0,19 (R)**	1,47 (R)	**8,84 (R)**	0,39 (S)	56,19 (S)	S2	S1
LMU 9	Clay	6,67 (N)	21,69 (ST)	0,21 (S)	1,56 (R)	**15,60 (R)**	**0,23 (R)**	**24,85 (R)**	S3	S3
LMU 10	Sandy Loam	6,50 (AM)	17,03 (ST)	0,38 (S)	3,13 (T)	**12,08 (R)**	**0,27 (R)**	**39,97 (R)**	S2	S1
LMU 11	Sandy Loam	5,85 (AM)	**11,86 (T)**	0,24 (S)	1,81 (R)	**7,43 (R)**	**0,37 (R)**	**38,90 (R)**	S2	S1
LMU 12	Sandy Clay Loam	6,04 (AM)	19,33 (ST)	**0,15 (R)**	1,07 (R)	**6,68 (R)**	**0,19 (SR)**	53,62 (S)	S2	S1
LMU 13	Sandy Loam	**5,00 (M)**	**14,94 (T)**	0,56 (T)	6,01 (ST)	**15,68 (R)**	**0,14 (R)**	**22,89 (R)**	S2	S1
LMU 14	Sandy Loam	5,50 (AM)	15,17 (ST)	**0,18 (R)**	1,17 (R)	**6,54 (R)**	**0,15 (R)**	**32,16 (R)**	S2	S1
LMU 15	Sandy Loam	5,35 (M)	17,67 (ST)	**0,16 (R)**	1,06 (R)	**6,29 (R)**	**0,10 (SR)**	**40,94 (S)**	S2	S1
LMU 16	Sandy Loam	6,26 (AM)	22,73 (ST)	**0,20 (R)**	1,34 (R)	**7,26 (R)**	**0,18 (R)**	55,87 (S)	S2	S1
LMU 17	Sandy Loam	5,75 (AM)	**10,35 (T)**	**0,14 (R)**	0,98 (SR)	**7,94 (R)**	**0,36 (R)**	**25,46 (R)**	S2	S1
LMU 18	Sandy Clay Loam	5,86 (AM)	**10,81 (S)**	0,49 (S)	4,21 (T)	**15,85 (R)**	0,43 (S)	**18,69 (SR)**	S2	S1
LMU 19	Sandy Loam	5,96 (AM)	17,86 (ST)	0,24 (S)	1,64 (R)	**9,21 (R)**	0,41 (S)	52,69 (S)	S2	S1
LMU 20	Sandy Loam	5,49 (M)	18,87 (ST)	0,25 (S)	2,22 (S)	**6,79 (R)**	**0,21 (R)**	**15,29 (SR)**	S2	S1
LMU 21	Sandy Loam	6,12 (AM)	15,06 (ST)	0,22 (S)	1,87 (R)	**5,94 (R)**	**0,20 (R)**	59,95 (S)	S2	S1
LMU 22	Sandy Clay Loam	5,69 (AM)	17,72 (ST)	**0,19 (R)**	1,26 (R)	**8,47 (R)**	1,02 (ST)	65,08 (T)	S2	S1
LMU 23	Sandy Loam	5,60	20,42	0,24	1,72	**9,62**	**0,17**	**35,51**	S2	S1

LMU	Texture	pH H_2O	P_2O_5	N-tot	C Org	CEC	K_2O	BS	Suitability	
			ppm	(%)	(%)	me /100g	me /100g	(%)	KA	KP
		(AM)	(ST)	(S)	(R)	**(R)**	**(R)**	**(R)**		
LMU 24	Sandy Loam	6,25 (AM)	19,93 (ST)	0,70 (T)	6,48 (ST)	**13,86 (R)**	0,91 (T)	**27,38 (R)**	S2	S1
LMU 25	Sandy Loam	6,17 (AM)	18,59 (ST)	0,45 (S)	3,70 (T)	**12,27 (R)**	0,40 (S)	**22,79 (R)**	S2	S1

Notes:

AM = A bit acid R = Low N = Neutral T = High

SR = Very low ST = Very high M = Acid S = Moderate

KA = Actual Land Suitability KP = Potential Land suitability

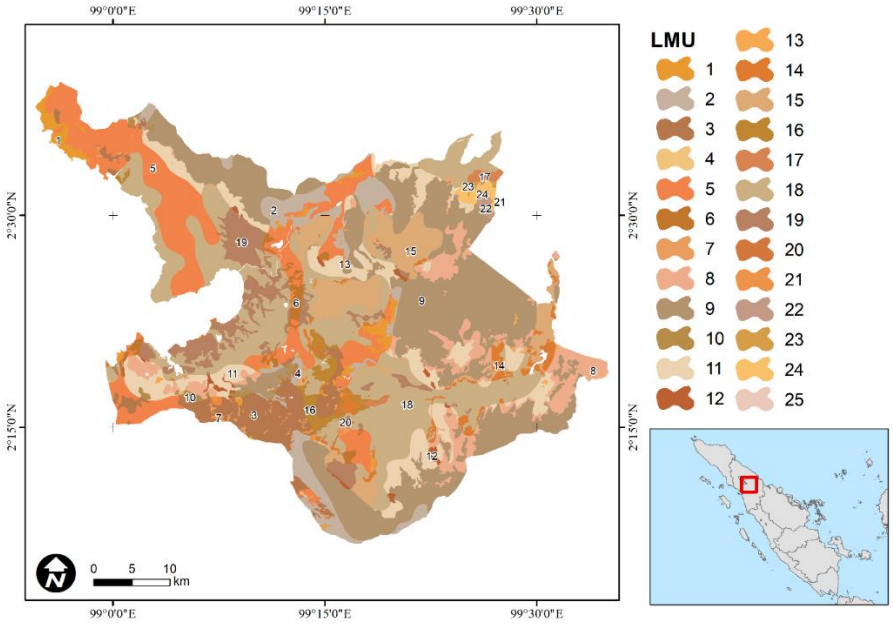

Figure 3. Research Land Map Unit (LMU) Map in Toba Regency.

The data analysis technique for determining subclasses of land suitability is a matching system between the growing requirements of Arabica coffee plants and the quality and characteristics of the land in the research area. The actual land suitability subclass is then classified according to the limiting factors in each land unit with improvement efforts at medium and high management levels, so that potential land suitability subclasses are produced in each land/land map unit. The land suitability classification based on the criteria, namely, S1 (Very Suitable), S2 (Suitable), S3 (marginal suitable), N1 (conditionally not suitable) and N2 (permanently not suitable).

3. Results and Discussion

The land characteristics in Toba Regency have a clay, sandy loam and sandy clay texture. Soil pH is slightly acidic, namely ranging from 5 – 6.67. P-available ranges from medium to very high, namely 10.35 -20.66 ppm. N – Total soil ranges from low to high, namely, 0.13 – 0.70%. Soil organic C ranges from 0.98 – 6.48%.

The actual land suitability for Arabica coffee plants is in the Sufficiently Suitable class (S2) with a limiting factor for Soil pH in the acid soil category (5.0-5.18) found in 2 Soil Map Units, namely LMU 1 and LMU 13 Where the appropriate soil pH for Arabica coffee fields is a soil pH of 5.3-6.0. Factors limiting soil pH can be improved by agricultural liming. So the suitability of potential land for coffee plants can be S1 (Very Suitable). Limiting Factor Soil phosphorus is only found in land at LMU 18 with a value of 10.81 (medium). Coffee plants

require an available P value of 15 ppm (high) so the shortage of available P elements on this land is 15 ppm minus 10.81 ppm (4.19 ppm). This limiting factor can be improved by adding P fertilizer as much as 4.19 Kg P/ha or 9.31 Kg SP36/ha or 11.63 Kg TSP/ha.

Phosphorus fertilizer doses usually range from 50 to 100 kilograms per hectare per year. Providing phosphorus fertilizer is generally done before planting or in the early stages of plant growth. From the results of soil analysis in Toba Regency, P fertilizer was only 4.19 kg per ha. The N-Total soil limiting factor is found in 9 (nine) soil map units, namely LMU 1, LMU 7, LMU 8, LMU 12, LMU 14, LMU 15, LMU 16, LMU 17 and LMU 22 with low values (0.13- 0.20 %). The appropriate N-Total value for coffee plants is medium (0.5%). So the shortage of N-Total elements on this land is 0.5% minus 0.2% (0.3%).

The total N requirement for Arabica coffee plants is around 200 kg, so 0.5% Nitrogen content is required, while the total N availability in the soil at the time of the study was 0.2%, so an addition of 0.3% (0.3 times 200 kg) is needed, which is equivalent to with 60 kg N/ha or 133.3 Kg Urea/ha. The total fertilizer needed for coffee plants in Toba Regency requires an average addition of 25% to meet microbial needs and N nutrient losses so it is necessary to add 25% x 60 kg of fertilizer, namely 15 plus 60 to 75 kg N/ha or 166,625 kg Urea/ Ha. In this way, the suitability for the total N becomes very suitable (S1) from the quite suitable class (S2). Applying nitrogen fertilizer can be divided into several stages, such as application at the beginning of the growing season and additional fertilization during the active growth period.

The limiting factor Potassium (K) is found in 16 Soil Map Units, namely SMU 1, SMU 5, SMU 6, SMU 7, SMU 9, SMU 10, SMU 11, SMU 12, SMU 13, SMU 14, SMU 15, SMU 16, SMU 17, SMU 20, SMU 21 and SMU 23. From the results of soil analysis in Toba Regency, potassium values are in the very low (0.10 me/100 gr) to low (0.3 me/100 gr) categories. The K requirement of coffee plants has a very suitable value if it meets a moderate K element content, namely 0.4-0.5 mg/100 g). Input improvements to the limiting factor of K fertilizer by adding 0.002 mg K/ha or 0.002/0.6 x 100 or 0.003 mg KCl. The dose of potassium fertilizer ranges from 100 to 200 kilograms per hectare per year. Potassium fertilizer can be applied regularly during the plant growth season.

The limiting factor for C-Organic is found in 5 Soil Map Units, namely SMU 1, SMU 12, SMU 14, SMU 15 and SMU 17 with soil analysis values of 0.98 to 1.14%. Where the C-Organic value in coffee plants is very suitable if the C-organic value is > 1.2%. If the desired organic C content is 1.2 then 1.2 is reduced by 0.98%, namely 0.22% x 2000 tons (soil weight) to 44,000 Kg C/ha or 44 tons C/ha. The limiting factor for this carbon deficiency is the addition of organic material or compost. If the compost has a C content of 24%, the compost requirement is 100/24 times 44 tonnes, namely 10.56 tonnes of compost/ha.

Providing balanced nitrogen, phosphorus and potassium fertilizer, according to the needs of Arabica coffee plants, can help increase productivity, coffee bean quality and plant resistance to unfavorable environmental conditions. Compost is also a valuable source of organic nutrients and can help improve long-term soil fertility. The function of Nitrogen (N) fertilizer on Arabica coffee plants is to stimulate vegetative growth of coffee plants such as leaves and branches, increase production and quality of coffee cherries, improve the green color of leaves, increase photosynthesis and crop yields.

The function of Phosphorus (P) Fertilizer in Arabica coffee plants is to help the development of a strong and healthy root system, increase flowering and fruit formation in coffee plants, increase the development of coffee beans and produce quality beans. The function of Potassium (K) Fertilizer in Arabica coffee plants is to increase plant resistance to environmental stress such as drought, disease and pest attacks, improve the quality of coffee beans, including taste, aroma and bean size, and increase plant resistance to diseases such as fungus. The function of compost in coffee plants is to increase soil fertility and structure, as well as improve water holding capacity, supply nutrients gradually and sustainably to coffee plants, and increase the activity of soil microorganisms and nutrient availability.

The actual land suitability value of coffee plants is divided into very suitable classes (S1) covering an area of 55,500.53 ha (26.74%), Fairly suitable with the limiting factor for nutrient retention (S2 nr) covering an area of 8,345.72 ha (4.02%), Fair in accordance with the limiting factor for nutrient retention and rooting media (S2 nrrc) covering an area of 936.67 ha (0.45 %), quite in accordance with the limiting factor for rooting media (S2 rc) covering an area of 3,839.87 ha (1.85 %), Fairly suitable with a temperature limiting factor (S2 tc) covering an area of 131,251.97 ha (63.25%) and marginally corresponding to a temperature limiting factor (S3 tc) covering an area of 7,643.54 ha or 3.68%.

The limiting factor of temperature cannot be improved. The potential land suitability class for coffee plants in Toba Regency becomes very suitable (S1) covering an area of 67,844.68 ha or 32.69%, moderate suitable class (S2) with temperature limitation covering an area of 132,030.09 ha or 63.62% and marginal suitability (S3 with temperature limitation) covering an area of 7,643.54 ha or 3.68%. Actual and potential land suitability classes for Arabica coffee plants in Toba Regency can be seen in Table 2. Maps of actual land suitability classes and potential land suitability for Arabica coffee plants in Toba Regency, North Sumatra Province, processed through the Geographic Information System (GIS) are presented in Figures 4.

Table 2. Actual and Potential Land Suitability Classes for Arabica Coffee Plants in Toba Regency

Actual Suitability Class	Total (ha)	Percent (%)	Potential Suitability Class	Total (ha)	Percent (%)
S1	55,500.53	26.74%	S1	67,844.68	3.69%
S2 nr	8,345.72	4.02%	S2 tc	132,030.09	63.62%
S2 nrrc	936.67	0.45%	S3 tc	7,643.54	3.68%
S2 rc	3,839.87	1.85%			
S2 tc	131,251.97	63.25%			
S3 tc	7.643,54	3.68%			
Total	**207.518,31**	**100.00%**	**Total**	**207.518,31**	**100.00%**

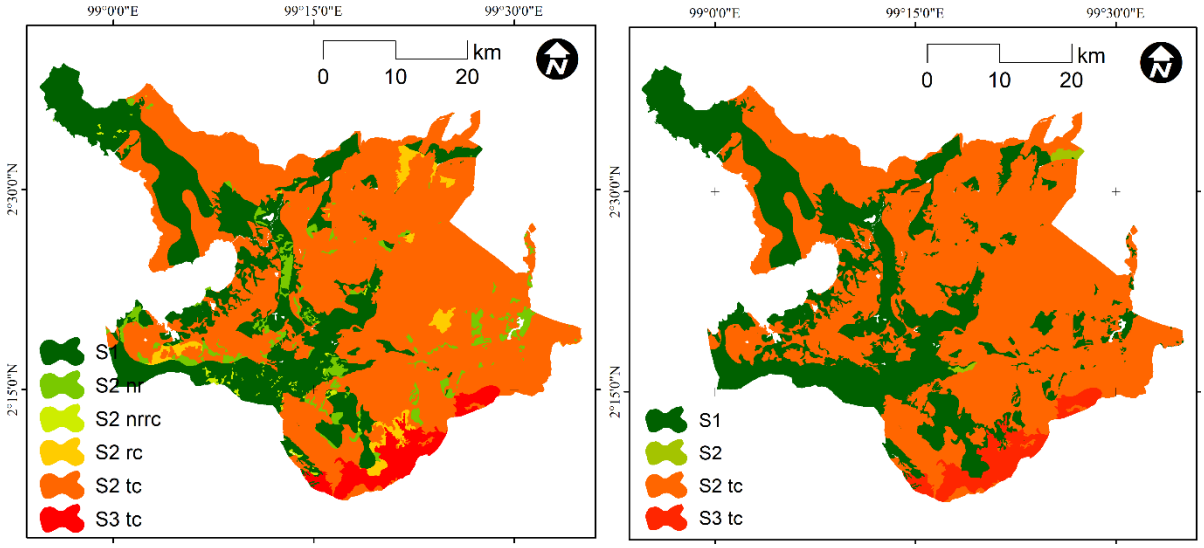

Figure 4. Actual (left) and Potential Land Suitability (right) for Arabica Coffee Plants in Toba Regency

4. Conclussion

The area of Toba Regency is 207,518.31 ha. Land Suitability class for Arabica Coffee Plants is very suitable class (S1) covering an area of 67,844.68 ha (32.69%), moderate class S2 covering an area of 132,030.09 ha (63.62%) with a limiting factor of temperature. The marginal appropriate class (S3) covers an area of 7,643.54 ha (3.68%). The limiting factor for nutrient retention was reduced by adding organic material, the limiting factor for low nutrient availability was reduced with fertilization, the limiting factor for high rainfall was reduced by creating drainage channels. The limiting factors of effective depth and temperature cannot be improved. The limiting factor of temperature cannot be improved. The potential land suitability class for coffee plants in Toba Regency becomes very suitable (S1) covering an area of 67,844.68 ha or 32.69%, moderate suitable class (S2) with temperature limitation covering an area of 132,030.09 ha or 63.62% and marginal suitability (S3 with temperature limitation) covering an area of 7,643.54 ha or 3.68%. The recommended fertilizer added from the results of soil analysis carried out in the Toba Regency area is phosphorus (P) fertilizer of 4.19 kg P/ha or 9.31 kg SP36/ha or 11.63 kg TSP/ha. Nitrogen (N) fertilizer is 75 kg N/ha or the equivalent of 166,625 Kg Urea/ha. Potassium (K) fertilizer as much as 3 kg KCl/ha. Compost fertilizer is 10.56 tons of compost/ha.

Author Contributions

Conceptualization, SN.; methodology, SG.; validation, SN.; formal analysis, SG.; investigation, RAW.;

resources, RAW.; data curation, SM.; writing—original draft preparation, SM.; writing—review and editing, HW. and SN; visualization, HW.; supervision, SN and HW..; project administration AN.; funding acquisition, AN All authors have read and agreed to the published version of the manuscript.

Informed Consent Statement

Not applicable.

Data Availability

Not applicable.

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Conflicts of Interest

The authors declare no conflict of interest

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