Assessment of Fertility Index Values of Various Marginal Soil Types

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Abstract: The soil fertility index (SFI) technologi is an assessment of soil properties and nutrient availability to support plant growth and development. The soil fertility index is very relevant in the engineering of planting media, especially on marginal land to support environmentally friendly sustainable agriculture by utilizing organic materials as soil improvers. This research contributes to crop cultivation by utilizing marginal land, by offering a method of analyzing soil fertility index and providing knowledge to oil palm farmers in utilizing marginal land as a planting medium. The purpose of this research is to analyze the fertility value of various marginal soils that will be used as planting media materials. This research was conducted in Musi Rawas Regency, South Sumatra Province, Indonesia, from November 2024 to January 2025. This research method uses disturbed soil samples on marginal land. Composite soil samples consisting of five types of marginal soils include: ultisol subsoil with a depth of M1 = 0-50 cm, M2 = 50-100 cm, M3 = 100-150 cm, peat and entisol. The results of the comparative study of the fertility value of various types of marginal soils are almost on average low criteria, for improvement it is necessary to add organic matter as much as 1.5 - 2.5% to each planting medium and evaluate the fertility index of various types of marginal soils ranging from 80 - 100 which is categorized in the low to medium class.

Keywords: Soil chemical, Suboptimal soil

Introduction:

Soil as a growing medium that provides nutrients, water, and a place to take root. The condition of the growing medium which includes physical, chemical, and biological properties has a significant influence on the results of farming. Planting media requires a large amount of soil for plant growth, considering that fertile land on topsoil which contains a lot of humus in Indonesia is decreasing, because crop cultivation activities are carried out continuously, without any effort to improve soil quality. Based on data from Rosnina[1] it was stated that in providing 150,000 oil palm seedlings, the requirement for topsoil growing media is 2,400 m^3 or equivalent to a land area of 1.6 ha with a topsoil depth of 15 cm. One of the many soils that have not been utilized by the farming community is marginal land. Marginal land is identical to land that has low quality, less productive and degraded land.[2] According to Wang et al. economically marginal land is land with low productivity that uses agricultural inputs including fertilization, irrigation, tillage, weeding, and other agronomic measures.[3] This is supported by the opinion of Mulyani et al. marginal land is land with low productivity or degraded land caused by internal and external factors.[4]

One of the plant nurseries that use a lot of soil, that is oil palm nurseries, especially fertile land topsoil, and ultisol topsoil as a planting medium. According to Dewi et al. explained that planting media is a source of nutrients needed by every plant.[5] To overcome this, it is necessary to carry out planting media engineering innovation technology using marginal or suboptimal soil, by mixing various growing media materials to increase the fertility of suboptimal soil. Planting media engineering is the design of planting media using various components of materials such as soil, cow manure, or other alternative materials such as husk charcoal, which are mixed in a certain ratio. The optimal growing medium is able to provide sufficient nutrients and support the plant growth process effectively.[6] The use of marginal land has good potential to support the growth of oil palm seedlings. According to Rozen et al. suboptimal land has a very low soil pH (4.09), low N nutrient content (0.11%), very low available P content (0.45 part per million), very low K content (0.42 miliekuivalen), very low C-organic content (0.94%), very low Ca content (0.75 miliekuivalen), high Fe content (8.95 part per million) and very high Al content (4.168 miliekuivalen).[7] Marginal or suboptimal lands consist of acidic drylands, arid drylands, tidal lands, wetlands, and peatlands.

Before using marginal land, a soil fertility index analysis should be conducted. Soil Fertility Index (SFI) is commonly used as a quantitative evaluation of soil fertility. According toAgustian et al. the assessment of soil fertility index has a very good relevance in describing indicators about determining the stability and improvement of agricultural production and the status of nutrients contained in the soil.[8] Physical and chemical indicators are often used to assess soil fertility status, but knowing the content of organic matter is also an indicator of analyzing soil texture and soil quality and the content of macro nutrients including Nitrogen (N), Phosphorus (P), Potassium (K) and Magnesium (Mg).[9] Soil fertility is an indicator of the soil's ability to provide essential nutrients in balanced conditions. The soil fertility index is related to soil quality. Meanwhile, according toBatu et al. soil quality is a description of the integration of suitability between elements of physical, chemical, and biological soil properties and their interactions.[10]

This study has differences compared to previous studies that have been conducted by several researchers, this study includes an analysis of the marginal soil fertility index, where this marginal soil is used as a planting medium for oil palm seedlings in the pre-nursery and main-nursery periods before oil palm seedlings are planted in the field, by knowing the value of soil fertility, it is hoped that it will be able to increase the fertility of marginal soil, so that when the soil is used as a planting medium in polybags, it can support the growth of oil palm seedlings. While previous studies have both analyzed the soil fertility index, but on the scale of a large land map unit in the field and the soil used is mostly fertile soil that has been degraded, to support agriculture in a sustainable manner, it is necessary to make efforts to utilize marginal lands by improving soil properties using soil improvers in the form of organic fertilizers from crop residues. The purpose of this study was to compare soil fertility values of different types of marginal soils and evaluate the fertility index of marginal soils and improve soil physical and chemical properties by applying various ameliorants. Based on the above description, researchers have analyzed soil fertility indices in the soil science laboratory of Bengkulu University to engineer planting media using various types of marginal land soils.

Materials and methods

This research was conducted in Musi Rawas Regency, South Sumatra Province, Indonesia, from November 2024 to January 2025. The first stage of the research method is soil fertility index analysis, by analyzing the properties of ulitis subsoil through testing 3 levels of depth, namely with a depth of 0-50 cm (M1), 51-100 cm (M2), and 101-150 cm (M3), peat soil from South Sumatra Province and soil from coastal areas (entisol) Bengkulu Province, each soil is taken by purposive sampling. Activities that have been carried out determine the location of ultisol subsoil, peat soil, and coastal area origin, preparation of soil sampling tools, and soil sampling at each location. various soil types are shown in Figure 1 below.

Figure-1. Various types of marginal soils

Soil sampling in this study used disturbed soil samples, taken randomly at 5 soil sampling points used as planting media for oil palm nurseries, to obtain 1 composite soil sample for each type of marginal soil (ultisol subsoil with a depth of M1 = 0-50 cm, M2 = 51-100 cm, M3 = 101-150 cm, peat and entisol), which was then subjected to soil chemical analysis at the Soil Science Laboratory of Bengkulu University. Soil analysis including N, P, K, Ca, Mg, Al, pH, C-organic, and CEC afterwards, the soil analysis results obtained were assessed by comparing them to the Criteria for assessing soil chemical properties Soil Research Center indicators as shown in Table 1.[11]

- **Analysis of soil chemical properties**

Table 1. Criteria for assessing soil chemical properties

Soil Properties		Very Low	Low	Medium	High	Very high
C (%)		< 1.00	1.00-2.00	2.01-3.00	3.01-5.00	>5.00
N (%)		< 0.10	0.10-0.20	0.21-0.50	0.51-0.75	>0.75
P_2O_5 Bray (ppm)		< 10	10-15	16-25	26-35	>35
CEC (mg/100 g^{-1})		< 5	5-16	17-24	25-40	> 4 0
Carbon Structure						
K (mg/100 g^{-1})		< 0, 1	0.1-0.2	0.3-0.5	0.6-1.0	>1.0
Mg (mg/100 g^{-1})		< 0.4	0.4-1.0	1.1-2.0	2.1-8.0	>8.0
Ca (mg/100g $^{-1}$)		< 2	2-5	6-10	11-20	>20
Al Saturation (%)		< 10	10-20	21-30	31-60	>60
pH H2O	Very Acid < 4.5	Acid 4.5-5.5	Somewhat acidic 5.6-6.5	Neutral 6.6-7.5	Somewhat alkaline 7.6-8.5	Alkaline > 8.5

Source: Soil Research Center (1983).

- **Assessment of soil fertility status.**

The formula used for the assessment of soil fertility index (SFI) used in this study is as follows:

SFI = (H CEC*B) + (H N*B) + (H C*B) + (H P*B) + (H K*B) + (H Ca*B) + (H Mg*B) - (H Al*B) with:

H = Harkat or Land Value
B = Weight
CEC = Klei CEC (me 100 g^{-1})
N = Total soil N (%)
C = Soil organic C (%)
P = Available P (part per million)
K = Exchangeable K (me 100 g^{-1})
Ca = Exchangeable Ca (me 100 g^{-1})
Mg = Exchangeable Mg (me 100 g^{-1})
Al = Al saturation (%)

Fertility index classification is divided into five classes: high, moderately high, medium, moderately low, and low with class range based on a uniform interval method.[12] This method is determined based on the equation: Class interval = (maximum value-minimum value)/number of classes. Based on this method, the classes were obtained:

- High = 241-280
- Somewhat high = 201-240
- Medium = 161-200
- Somewhat low = 121-160
- Low = 80-120

- **Data processing.**

  The data that has been obtained is then analyzed descriptively regarding the relevant parameters. In addition, descriptive statistical analysis to facilitate understanding of the influence of the determinants of soil fertility.[13]

Results

The data results of fertility index analysis of various types of marginal soils conducted in this study are as follows:

- **Analysis of soil chemical properties**

Table 2. Research data from the assessment of marginal soil fertility

Soil Type Marginal (M)	C	N	P	K	Ca	Mg	Al	CEC	pH
	(%)		(ppm)	(me/100 g)					
M1 (Sub-ultisol 0-50 cm)	1.41	0.09	5.31	0.36	0.22	0.44	3.32	9.80	4.77
M2 (Sub-ultisol 51-100 cm)	1.34	0.12	4.97	0.24	0.21	0.33	2.77	16.06	4.82
M3 (Sub-ultisol 101-150 cm)	0.96	0.07	0.45	0.20	0.19	0.21	2.16	18.91	4.65
M4 (Peat/Histosol)	26.75	0.32	9.09	0.35	0.65	0.07	4.81	128.92	3.27
M5 (Entisol)	0.53	0.06	3.85	0.31	1.81	0.18	0.37	7.31	7.34

Source: The Soil Science Laboratory of Bengkulu University 2024

Based on the results of the analysis of various marginal soils in Table 2 by comparing using indicators from the Soil Research Center in Table 1. shows that peat soil types have the highest C-organic content, nutrients N, P, K, and pH 3.27 with very acidic soil status. While sub-ultisol soil with a soil depth of 101-150 cm has the lowest nutrient content in nutrients P, K, and Ca with acidic soil status.

- **Soil fertility index**

Table 3. Fertility index of various marginal soils based on classification using formula

Soil Type	H* B_N	H* B_C	H* B_P	H* B_Al	H* B_K	H* B_Ca	H* B_Mg	H* B_CEC Klei	SFI Score	Class SFI
M1 (Sub-ultisol 0-50 cm)	10	40	20	5	40	10	10	5	140	SL
M2 (Sub-ultisol 51-100 cm)	10	40	20	5	20	10	10	10	125	SL
M3 (Sub-ultisol 101-150 cm)	10	20	20	5	20	10	10	10	105	L
M4 (Peat)	20	60	20	5	40	10	10	15	180	M
M5 (Entisol)	10	20	20	5	40	20	10	5	130	SL

Description L : Low, SL: Somewhat Low, M: Medium, SFI: Soil Fertility Index.

Based on the results of the marginal soil fertility index in Table 3, peat soil types with a score of 180 are included in the moderate soil fertility index. While sub-ultisol soil with a soil depth of 101-150 cm with a score of 105 is included in the low soil fertility index. Oil palm nursery is the initial stage of activities that must be started a year before moving to the field, in addition to genetic factors from superior varieties that need to be considered, environmental factors are supporting factors in plant cultivation, one of which is the use of planting media to produce quality oil palm seedlings. For utilization of marginal land soils as a medium for plant, it is better to first improve the physical, chemical, and biological properties of the soil in various types of soil to be used such as various depths of ultisol subsoil, peat soil and entisol soil from coastal areas considering that these marginal land soils have many limiting factors.

Disucssion

- **Analysis of soil chemical properties**

C-organic.C-organic describes the amount of organic matter content in the soil. Carbon is a food source for soil microorganisms, therefore, the presence of organic carbon in the soil can spur the activity of microorganisms, which in turn increases the process of soil decomposition and reactions involving organic matter in the soil. Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that sub-ultisol soils with a depth of 101-150 cm and entisol soils show the content of organic matter contained in them at low criteria. While subultisol soil with a depth of 0-100 cm is included in the medium criteria, peat soil has a content of 26.75% with very high criteria. According to the

Soil Research Center. the optimal standard for improving soil chemical properties with the percentage of carbon content (C) with an assessment of 2.01-3.00 with a medium content category.[11] For this reason, before the soil media is used, the addition of organic materials such as animal manure or compost is recommended. According to Azmul et al. argue that organic matter has a very important role in soil, especially in influencing changes in its properties, be it physical, biological, or chemical properties, besides that as a granulation form, organic matter contributes significantly to creating stable soil aggregates.[14] Meanwhile, according to Nurhidayati. organic matter has a very close relationship with the availability of nutrients in the soil.[15]

Nitrogen (N). Nitrogen is an essential nutrient required by plants. Nitrogen is needed in large quantities during the growth phase of vegetative organs. Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the N content in the marginal soil of sub-ultisol 0-50 cm, sub-ultisol 101-150 cm, and entisol has a very low nitrogen nutrient content status, while sub-ultisol 51-100 cm has a very low nitrogen nutrient content status and peat has a moderate nitrogen content criteria. Nitrogen is absorbed by plants in the form of NO_3- or NH_{4+} ions from the soil. Nitrogen plays a very important role, especially in the essence of chlorophyll formation. Chlorophyll is considered an “engine” for plants because of its ability to synthesize carbohydrates that support plant growth. According toMarlina et al.the presence of nitrogen in plant structures is influenced by several factors, especially the availability of water and the presence of nutrients in the soil, especially nitrogen.[16] Nitrogen plays the most important role in various physiological processes.[17] After knowing the nitrogen nutrient content of each marginal soil, there will be an addition of nitrogen fertilizer to the soil in the form of urea fertilizer or Nitrogen, Phosphorus and Potassium (NPP) compound fertilizer.

Phosphorus (P). Phosphorus is one of the macro essential nutrients for plants. Phosphorus (P) is an important macronutrient for plant growth and development. The main source of phosphorus is phosphate rock. Based on the results of the marginal soil analysis test at the soil laboratory, it can be explained that the P content in all marginal soils has a very low nutrient content status. In plants, low P conditions trigger various morphological, physiological, biochemical, and molecular responses.[18] Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the P content in marginal soils shows overall in all types of marginal soils with very low nutrient content status. According toLubis et al. insufficient P supply causes plants to not grow optimally.[19] After knowing the phosphorus nutrient content of each marginal soil, there will be an addition of phosphorus fertilizer to the soil in the form of Triple Super Phosphate (TSP) fertilizer or Nitrogen, Phosphorus and Potassium (NPP) compound fertilizer.

Potassium (K). Potassium is an essential macronutrient along with N and P. Potassium plays an important role in various processes, such as photosynthesis, protein synthesis, regulation of stomatal opening and closing, and osmoregulation. Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the K content in the 51-150 cm sub-ultisol has a low nutrient content status, while the 0-50 cm sub-ultisol, peat, and entisol with moderate nutrient content status. According toWang et al.potassium has a very important role in biophysical and biochemical processes, which can affect plant growth and development, including the ability of plants to deal with biotic and abiotic stress, enzyme activation, regulation of cell osmoregulation, and control of stomatal opening in the photosynthesis process.[20] After knowing the phosphorus nutrient content of each marginal soil, there will be an addition of phosphorus fertilizer to the soil in the form of Kalium Clorida (KCl) fertilizer or Nitrogen, Phosphorus and Potassium (NPP) compound fertilizer. **Secondary macro nutrient content:** Secondary macro-nutrients are nutrients required by plants in smaller amounts than primary macro-nutrients to enhance plant growth. Macro nutrients consist of calcium (Ca), magnesium (Mg), and sulfur (S). According toTriadiawarman et al. plants need two types of nutrients, namely macro and micronutrients, to support optimal growth.[21] Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the secondary macro content, for calcium (Ca) and magnesium (Mg) nutrients in all marginal soils has a very low nutrient content status. This is supported by the opinion ofAdotey et al. that abnormal growth is caused by an insufficient amount of nutrients, thus limiting cell elongation and replication, resulting in inhibition of growth, deformation, or the appearance of wrinkled leaves.[22] To support plant growth, it is necessary to apply secondary macro-nutrient fertilizers.

Aluminum (Al). Aluminum is a non-essential element for plant growth, increasing aluminum solubility along with a decrease in pH to below 5 causes this element to need special attention because it can be toxic to plants. According toParjono et al. Al is an exchangeable form of Al_{3+}. High concentrations of Al in the soil will increase soil acidity through hydrolysis reactions and are toxic to plants.[23] High Al levels theoretically affect the availability of phosphorus (P) in the soil, as P can be precipitated by Al in the soil solution. Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the Aluminum (Al) content in all types of marginal soil has a very low category. To overcome this, it is necessary to add dolomite fertilizer to the soil. The most easily observed symptom of aluminum poisoning is the inhibition of root growth, which results in disturbances in nutrient absorption, which results in inhibition of plant growth. Symptoms that appear in plants that experience aluminum poisoning include inhibition of root growth, and changes in plant morphology.[24]

Cation exchange capacity (CEC). Soil Cation Exchange Capacity (CEC) is one of the chemical properties that has a significant role in maintaining and improving soil fertility. Cation exchange capacity is the exchange process between one cation contained in a solution with other cations on the surface of any active material. According toSarah et al. the finer the soil texture, the greater the amount of colloidal clay and colloidal organic, which causes the Cation Exchange Capacity (CEC) to also increase, and vice versa.[25] Based on the results of the marginal soil analysis at the soil laboratory, it can be explained that the cation exchange capacity on marginal soils for subultisol 0-50 cm and sub-ultisol 51-100 cm and entisol soils are still classified as low, and subultisol 101-150 cm is high and peat soils include very high CEC. High CEC, if followed by cation balance (Ca, Mg, K), can improve nutrient uptake by plants and overall plant growth. Cation imbalance at low CEC can cause competition between nutrients and reduce the availability of certain nutrients. The complexity of soil absorption capacity in binding cations increases in line with the high CEC (Cation Exchange Capacity). According to Gmitrowicz-Iwan et al. cation exchange is the most effective regulatory mechanism that affects the availability of macro and microelements.[26]

Potential of hydrogen (pH). The potential of hydrogen (pH) is a measure of the concentration of hydrogen ions in a solution. Solutions that have low pH values are referred to as “acidic”, while solutions that have high pH values are referred to as “basic”. Tropical and subtropical regions have acidic soils (pH $\leq$5.5) which show a high concentration of Al.[27] Based on the results of the marginal soil analysis at the, it can be explained that the soil pH on marginal soils for 0-150 cm subultisol soils are included in acidic soils, while peat soils have a very high soil pH. While peat soil has a very acidic soil pH and entisol soil is classified as neutral soil. To increase soil pH to neutral, it is necessary to add dolomite fertilizer to the soil. According to Stefanie et al. in acidic soils, the number of H^+ ions is higher than OH^- ions, while in alkaline soils, the content of OH^- ions is much more than H^+ ions. When the number of H^+ ions is equal to the number of OH^- ions, the soil reacts neutrally, which is characterized by pH = 7.[28] Soil pH reactions that are past the optimal limit can result in a decrease in the amount of availability of certain nutrients and sometimes can also cause excess availability of other nutrients

- **Soil fertility index**

  Based on the results of the marginal soil analysis soil laboratory, with a comparison of soil value indicators compiled byRomadhon and Hermiyanto. through the soil fertility index analysis method, low, rather low and moderate soil fertility values were obtained, so it is necessary to make efforts to improve soil properties to overcome limiting factors and increase soil fertility, to achieve maximum plant growth.[29] The soil fertility index is one of the techniques to assess the level of soil fertility on land. Meanwhile, according toLiang et al. a comprehensive assessment of soil nutrient status is very important to improve crop productivity, in addition to maintaining environmental quality, ecological balance, and organism health.[30]

  Based on the table above of the fertility index results of various types of marginal soils obtained from various locations includes subultisol soil with a depth of 101-150 cm with low fertility status, while sub-ultisol soil with a depth of 0-100 cm and entisol soil from the Bengkulu coastal area with a rather low fertility status, then peat soil with a medium category soil fertility status. Differences in the use of various types of marginal soils as planting media for oil palm nurseries cause differences in soil fertility index values. The use of marginal soils for nursery activities currently causes problems related to the low growth rate of seeds, which results in the seedlings becoming unfit for planting in the field, due to their growth that does not meet the standards. The problem faced on marginal land is related to soil fertility. One of the efforts to overcome this problem is by engineering the planting media using organic materials and soil conditioners during the seedling process. One of the roles of organic matter is to improve the biological properties of the soil, which can increase the activity of microorganisms so that they can release humic, fulvic, carboxyl, phenol and other organic acids that react to Al, Fe, and Mn metals and nutrients can be available to plants. Soil improvers can be used to improve soil aggregates to prevent erosion, increase the capacity of soil to retain water, and increase the ability of soil to store nutrients by increasing Cation Exchange Capacity.[31]

The ideal growing medium for optimal plant growth should be able to improve soil physical, soil chemical, and soil biological properties. The results of the soil fertility index on various types of marginal soils that have been analyzed show that the status of soil fertility needs planting media engineering, one of which is by utilizing organic fertilizers and soil improvers, especially on sub-ultisol and entisol in further research the oil palm seedling media to be used is first applied cow dung fertilizer using standard indicators of increasing C-organic and improving soil pH according to the reference from the Soil Research Center. with moderate category assessment criteria. Marginal soils used as planting media before planting sprouts are applied cow dung fertilizer with a calculated dose of 1.5-2.5% equivalent to 75-150 grams per planting media. Meanwhile, to increase the pH of marginal soils that are very acidic and acidic to the standard slightly acidic to neutral or pH 6-7.5 through the addition of dolomite at a dose of 1-1.5 grams per planting medium. According toBrady et al. soil pH is described as a “key soil variable” that affects a myriad of biological, chemical, and physical soil properties and processes.[32] Which can improve plant growth and biomass yield. According to Zhang and Yang if soil pH is too low or too high, the availability of these nutrients decreases, and plants can experience nutrient deficiencies.[33]

Conclusion:

Soil fertility index analysis can be concluded : The results of the comparison of the fertility value of various types of marginal soils are almost on average low criteria, for improvement it is necessary to add organic matter as much as 1.5-2.5% in each planting medium and evaluate the fertility index of various types of marginal soils ranging from 80-200 which are categorized in the low to medium class.

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