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Limiting factor for developing soybean under tropical climatic conditions in lowland areas of Tanjung Lago Banyuasin District

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ABSTRACT

Tidal lowlands have a wide distribution in Indonesia and have the potential to support the development of soybean cultivation. However, soybean cultivation in the tidal lowlands often faces various challenges. The study aimed to identify land suitability, limiting factors, and soybean cultivation strategies in tidal lowland type B. This study used a survey method, and sampling points were determined by the purposive sampling method. The research was carried out in several stages, namely preparation, field activities, laboratory analysis, and data analysis. Data analysis was carried out by matching the results of field and laboratory analysis with the requirements for soybean land suitability. The results of the study showed that the research land was moderately suitable for soybean cultivation in terms of the actual land suitability level, namely S3-wa, nr, na, and xs with limiting factors of rainfall, soil pH, C-Organic, K_2O, and pyrite depth. While the potential land suitability class could be done by improving irrigation and drainage channels, liming, adding organic matter, fertilization, and regulating the water level with high-level management (++) to potential suitability S1 (very suitable) and for pyrite problems (FeS_2) through moderate management (+) with groundwater level control to potential suitability S2 (moderately suitable). Management recommendations that can be applied to soybean cultivation were to regulate planting patterns and micro water management.

Keywords: drainage channels, *Glycine max*, land suitability, soybean crops, tidal lowland

INTRODUCTION

Soybean (*Glycine max* L.) was one of the food commodities in Indonesia (Nasikh et al., 2021). This plant had morphological characteristics such as a taproot, bushy stem, compound leaves, flowers that are white and some that are purple, and seeds that are round, oval, and flat (Shilpashree et al., 2021). Soybeans are also one of the sources of high-quality protein (Qin et al., 2022). The demand for soybeans in Indonesia had always shown an increasing trend every year (Ningrum et al., 2018). However, the trend of increasing demand does not match the declining domestic production figures, causing the government to be forced to import soybeans from abroad. As explained by (Manogna & Kulkarni, 2024), developing countries like Indonesia have low food self-sufficiency, are more dependent on imports, and are more reliant on foreign aid. Therefore, it was necessary to optimize soybean cultivation in Indonesia to reduce dependence on imports.

Tidal lowlands are suboptimal lands located in Indonesia (Ratmini et al., 2021). The tidal lowlands in Indonesia cover an area of 8.92 million hectares, categorised into 7.56 million hectares of mineral soil and 1.36 million hectares of peat soil (Zahra et al., 2024). The tidal lowlands, which cover a significant area in Indonesia, have great potential for agricultural development and are also very strategic in supporting food security efforts in Indonesia (Fahmid et al., 2022). Tidal lowlands are characterised by a water management system consisting of two parts: macro water management, which includes primary and secondary channels, and micro water management, which includes tertiary, quartile, and micro channels (Imanudin et al., 2024).

Tidal lowlands have potential in the development of soybean cultivation. However, the productivity of the harvest was sometimes limited by various constraints. Research that had been conducted by Pujiwati et al. (2017) on tidal lowland, soybean production always shows low yields, mainly due to land-limiting factors. These limiting factors include soil acidity and soil fertility (Susilawati et al., 2023), layer of pyrite and high salinity (Mardiansa et al., 2024), and economic factors such as the low market price for local soybeans (Iskandar et al., 2024). The interaction between genetic factors and environmental management will indeed affect the potential yield of soybeans in the field (Ghulamahdi et al., 2025). Therefore, strategic efforts are needed such as improving soil quality and processing, regulating water levels in channels, and developing quality varieties to address these limiting factors (Cheţan et al., 2022). Research conducted by (Rozi et al., 2025) also shows that tidal lowlands have the potential to become a national soybean centre if the management of limiting factors was carried out optimally.

Land suitability evaluation was a step to determine the potential of land in supporting crop productivity (Moisa et al., 2022a). Information regarding physical and chemical characteristics as well as attribute data was needed in land surveys and evaluations as a means of developing land use plans (Hagos et al., 2022). The results of the land suitability evaluation will yield actual suitability classes and potential suitability classes (Rahmawaty et al., 2024) which could serve as a reference for farmers in the development of agricultural commodities. Research on soybean cultivation in tidal lowlands remains limited, often concentrating on cultivation outcomes under specific treatments without addressing land suitability criteria.

The objective of this research was to evaluate the suitability of tidal lowlands for soybean cultivation, with particular emphasis on the Banyuasin region in South Sumatra. Specifically, it assesses both the actual and potential suitability of tidal lowlands for soybean production. The findings of this study are intended to inform land use planning and contribute to the strategic development of soybean cultivation in tidal lowland areas.

MATERIALS AND METHODS

Research Location

This research was conducted in tidal lowland Sukatani Village, Tanjung Lago District, Banyuasin Regency, South Sumatra. The research site was located at coordinates 104˚45’10.351”–104˚44’57.630”E and 2˚43’46.701”–2˚43’52.033’’S. Sukatani Village was located at the 19th primary bridge, Delta Telang II, Tanjung Lago District. Administratively, the boundaries of Sukatani Village to the North were adjacent to Mulya Sari Village, to the South were adjacent to Muara Sugih Village, to the East were adjacent to Sri Menanti Village, and to the West were adjacent to Tanjung Lago Village. Sukatani Village was one of the areas for the large-scale resettlement of people from Java Island that took place between 1969 and the 1980s. Laboratory research was carried out in the Physics Laboratory, Chemistry and Soil Fertility Laboratory, Department of Soil Science, Faculty of Agriculture, Sriwijaya University.

Method

The research employed a detailed survey method over an area of approximately 7 hectares, using a 1:5000 scale map as the primary medium. Soil sampling was conducted using a purposive sampling technique, with three sample points selected per hectare and subsequently composited. Purposive sampling involves pre-determining sampling locations based on specific characteristics that align with the research objectives (Girsang et al., 2021). As a result, a total of seven composite soil samples were analyzed in the laboratory (Figure 1).

Data Analysis

Analysis of the data obtained was conducted using the Matching analysis system, which was the process of evaluating land determined by matching land characteristics with the needs and requirements for soybean plant growth (Wahyunto et al., 2016). The analysis results were adjusted based on the growth requirements of soybean plants obtained from the reference

(FAO, 1976) in the technical guidelines for land evaluation by the Agricultural Land Resources Research and Development Center, 2016 edition. Land suitability table for soybean cultivation (Table 1).

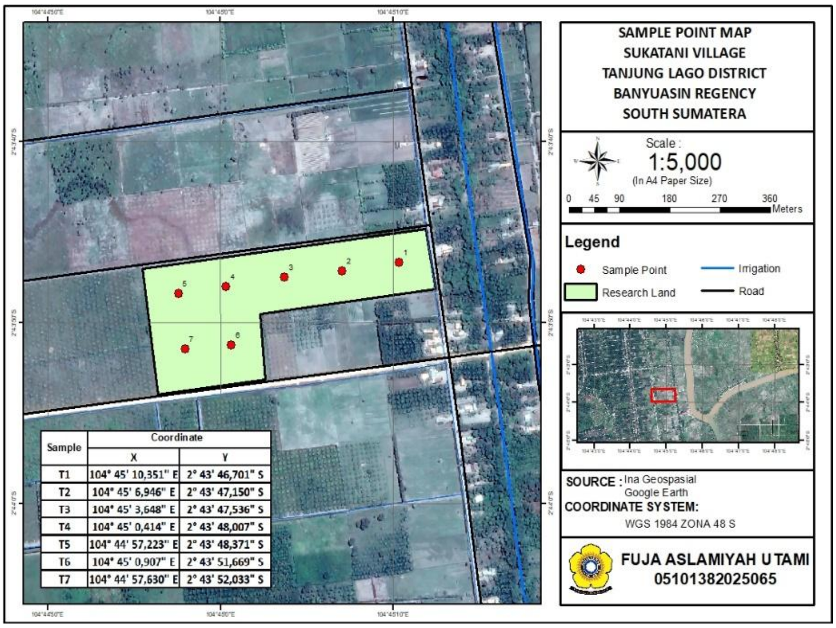

Figure 1. sample point map

Table 1. The criteria for determining the land suitability for soybean (FAO, 1976)

Land Characteristic	Land Suitability Class			
	S1	S2	S3	N
Temperature (tc)				
Temperatur Average (˚C)	23–25	20–23 25–28	18–20 28–32	<18 >32
Water Availability (wa)				
Rainfall (mm)	350–1.100	250–350 1.100–1.600	180–250 1.600–1.900	<180 >1.900
Root Media (rc)				
Texture	Fine, somewhat fine, medium	Fine, somewhat fine, medium	Moderately coarse	Coarse
Soil Depth (cm)	>50	30 – 50	20–30	<20
Nutrient Retention (nr)				
CEC Soil (cmol)	>16	5–16	<5	-
pH H_2O	5.5–7.5	5.0–5.5 7.5–7.8	<5.0 >7.8	-
C-Organik (%)	>1.2	0.8–1.2	<0.8	-
Nutrients Available (na)				
N Total (%)	Moderate	Low	Very low	-
P_2O_5 (mg/100 g)	High	Moderate	Low – Very low	-
K_2O (mg/100 g)	High	Moderate	Low – Very low	-
Sulfidic Hazards (xs)				
Sulfidic Depth (cm)	>100	75–100	40– 5	>40
Danger of Flooding During Planting (fh)				
Flood Depth	-	-	25	>25
Flood Period	-	-	<7	≤7

Note: S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N: Not suitable
Source: Land Suitability Assessment Guidelines for Strategic Agricultural Commodities Semi Detailed Level 1:50.000 Scale (Wahyunto et al., 2016)

RESULT

General Condition of the Tidal lowland in Sukatani Village

The area of the village was 1920 Ha and was used for the cultivation of food crops and horticulture, particularly for rice, palm oil, vegetables, and fruits. The people of Sukatani village, since the transmigration was carried out, many have started cultivating rice. This was because Delta Telang II was an area close to the river and influenced by the tidal movements of the sea, which ensures a year-round water supply for the plants. This was why the Delta Telang II area had become one of the largest and most potential agricultural centers in South Sumatra.

The land at the research location was rice paddy fields that experience annual diversification of agricultural cultivation carried out by local farmers. Cultivation on rice fields in tidal areas makes water availability the main benchmark for the development of certain agricultural commodities. In Figure 2, the condition of the land during the dry season was shown the land does not experience flooding, and farmers usually cultivate crops such as watermelon, melon, cassava, and vegetables. Meanwhile, during the rainy season, the high floods in the rice paddy areas were very strategic for rice cultivation. The soils in Sukatani village were characterised by acid sulphate soils with an average layer of pyrite at shallow depths, which often becomes a major problem for farmers (Figure 2). In addition to soil acidity issues, Sukatani village also faces challenges such as inadequate water management systems, which could lead to flooding in land events due to the limited number of sluice gates and the irrigation system management that was not yet well understood by farmers and local residents.

The irrigation infrastructure in Sukatani Village was generally in satisfactory condition, with established irrigation and drainage channels serving the agricultural activities of local residents. However, at the time of the study, the main drainage channel (Saluran Drainase Utama or SDU) was found to be in a state of neglect and functioning inadequately. The presence of unmanaged wild vegetation frequently impeded water flow, resulting in unidirectional drainage. Considering the critical role of the SDU in supporting rice cultivation and other horticultural activities, it was imperative that local authorities and land-owning farmers take immediate and coordinated action to address these issues.

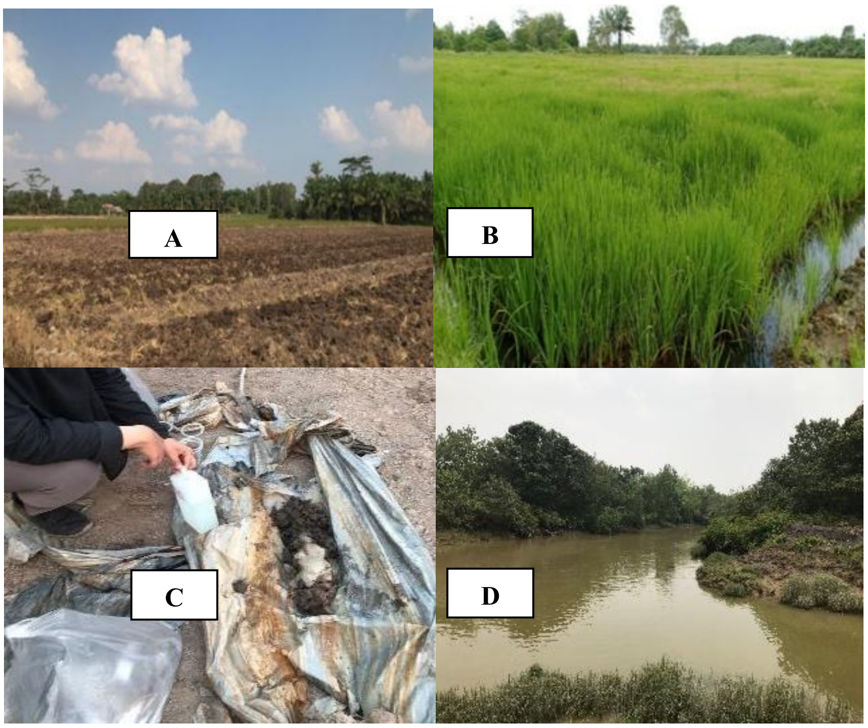

Figure 2. Land Conditions: (A) Land condition when dry, (B) Land condition when flooded, (C) Pyrite layer in acid sulfate soil, (D) Condition of the Village Irrigation Channel (SPD)

Climate Conditions

Climate was the main criterion in determining the land suitability class to support the productivity of crop cultivation in a region. The state of the climate was closely related to temperature, rainfall, humidity regime, and duration of sunlight. The climate conditions in Table 2.

Table 2. Climate Data at the Research Location (2014-2023)

Year	Temperature (˚C).	Rainfall (mm)
2014	27.60	1651
2015	27.70	2028
2016	27.80	3485
2017	27.50	2680
2018	27.50	2526
2019	27.80	2028
2020	27.60	2666
2021	27.52	2942
2022	27.76	3286
2023	28.87	2317
Average	27.76	2560

Sources: South Sumatra Provincial Climatology Station Data (2014-2023)

Temperature had an influence on plant growth and productivity and was one of the indicators in measuring land suitability. Temperature was very important to support plant productivity. The average air temperature from 2014 to 2023 was 27.76 degrees Celsius, according to data from the research location, the land falls under the criteria of Moderately Suitable (S2) and was moderately suitable for soybean cultivation.

Rainfall was also an important factor in soybean cultivation and must be included in land suitability analysis. The availability of rainfall was closely related to the water supply for soil and plant needs; rainfall data will also provide information on the irrigation and drainage systems that should be implemented on the land. At the research location, the average annual rainfall from 20 to 2023 was 2,560 mm/year. Based on this, the rainfall at the research location falls into the S3 suitability class (Marginally suitable). The availability of rainfall had a significant relationship with the water supply needed for soil and plants. According to Jabal et al. (2022) the research states that crop yields in the area were highly dependent on changes in rainfall patterns.

The research location had low rainfall during the dry season, but when the rainy season occurs, the research location could experience flooding because it falls into the type B overflow tidal land. Integrated water management was very necessary to be implemented, especially in tertiary channels that serve as water supply for tidal wetlands.

Temperature and rainfall could fundamentally affect plant growth and productivity and also one of the indicators in assessing land suitability (Moisa et al., 2022b). Temperature and rainfall were very important to support crop productivity, both before and after harvest. Natural phenomena such as rising temperatures and extreme climate changes often occur in Indonesia's tidal lowlands (Wang et al., 2021). To reduce the impact of climate change and rising temperatures, farmers and land users in tidal areas generally implement agricultural systems that were in accordance with the seasons and weather.

Root Media (rc)

Root media plays an important role in supporting plant growth. The results of the soil texture analysis in Table 3.

Table 3. Soil texture analysis

Sample	Texture Class	Suitability Class
1	Sandy Clay Loam [sf]	S1,
2	Sandy Clay Loam [sf]	S1,
3	sandy clay [mc]	S3,
4	Sandy Clay Loam [sf]	S1,
5	Sandy Clay Loam [sf]	S1,
6	Sandy Clay Loam [sf]	S1,
7	Sandy Clay Loam [sf]	S1,

Note: [sf]= Somewhat fine; [mc]= Moderately coarse

The average soil texture at the research location falls into the Sandy Clay Loam texture class and was categorized as highly suitable land for soybean growth, considering that soybeans require a growing medium in the form of clay or clay loam soil for the suitable category (Radocaj et al., 2020). Soil texture greatly influences plant growth, as soil texture could affect the ability of plant seedlings to grow. According to Benvenuti & Mazzoncini, (2021) that soil texture affects the level of inhibition. The inhibition mediated by soil depth was highest in clay soil, moderate in loamy soil, and low in sandy soil. The limiting factor in the form of soil texture in sample 3, which had a sandy clay texture, cannot be improved because soil texture generally requires a considerable amount of time, similar to the formation of soil that begins through the process of weathering (Rosmaiti et al., 2019).

Soil depth measurements were conducted directly at the research site using a Belgian auger. Based on field observations, the soil depth condition was 60 cm and had a Very Suitable (S1) class for soybean plant growth. Soil depth was an indicator for plants to distribute roots within the soil and soil depth, improve drainage capacity, and manage fertilization. In soil with a depth of more than 60 cm, it will allow soybean roots to grow well, enabling optimal water and nutrient absorption in the soil. Sufficient soil depth enhances plant stability and supports physiological functions, such as nutrient absorption and transpiration (Liebhard et al., 2022). Therefore, the soil properties at this research site promote ideal soybean growing.

Sulfidic Hazards (xs)

The results of sulfidic hazard observations in the field in (Table 4) show varying results. In samples 1, 2, 6, and 7 the pyrite layer was at a depth of 40 cm, while samples 3, 4, and 5 have a depth of more than 50 cm.

Table 4. The results of pyrite depth (cm)

Sample	Pyrite Depth (cm)	Suitability Class
1	43	S3
2	45	S3
3	55	S3
4	65	S3
5	60	S3
6	40	S3
7	40	S3

The results of the sulfide hazard observation indicate that the pyrite depth falls into the shallow pyrite category with varying depth results. These results indicate that the pyrite condition falls into the marginally suitable land class (S3) category and becomes the main limiting factor in soybean cultivation in tidal lowland areas. The soil condition falls into the category of acid sulfate, where the pyrite layer could oxidize at any time, especially when the land was dry. Pyrite was not harmful when the land was submerged, but it will be harmful to plants when the land was dry, due to the oxidation process of pyrite which was closely related to the acidity of the soil (Salo et al., 2023). Therefore, in soybean cultivation, soil management must be carefully considered to prevent the pyrite layer from coming into contact with air, which would cause the pyrite oxidation process. In addition, the management of the groundwater table must also be regulated by farmers during soybean cultivation.

Nutrient Retention (nr)

Nutrient retention includes soil pH conditions, cation exchange capacity (CEC), and soil organic c content. The results of the analysis were in Table 5.

Table 5. The results of the nutrient retention analysis

Sample	pH H_2O	C-Organik (%)	KTK (me/100 gr)
1	4.00 [VA]	2.84 [M]	19 [M]
2	4.28 [VA]	2.18 [M]	24.46 [H]
3	3.53 [VA]	1.98 [L]	21.75 [M]
4	3.59 [VA]	2.33 [M]	24.46 [H]
5	3.77 [VA]	1.67 [L]	19 [M]
6	3.25 [VA]	3.27 [H]	16.31 [M]
7	4.10 [VA]	2.22 [M]	24.46 [H]

Note: [VA]= Very acid, [L]= Low, [M] = Moderate, [H]= High
Sources: Technical guidelines edition 3: Chemical analysis of soil, plants, water and fertilizers (Kementerian Pertanian Republik Indonesia, 2023).

The limiting factor of very acidic soil pH in tidal areas was usually caused by a shallow and oxidized pyrite layer, especially under aerobic conditions. The presence of iron sulfide minerals becomes more dominant, making the soil conditions acidic and potentially affecting plant productivity (Ifansyah et al., 2023). The most appropriate management of the pyrite layer could be carried out by controlling the groundwater level and applying ameliorants such as lime, so that the soil pH could return to neutral and increase the land suitability class by two levels from S3 to S1 (Subiksa & Sukristyonubowo, 2021).

Organic matter plays an important role in fertilizing the soil. According to (Rocci et al., 2021) the organic matter found in the soil layers plays a significant role in improving the physical, chemical, and biological properties of the soil. The organic matter content at the research site was very suitable for supporting soybean plant growth.

The cation exchange capacity of the soil at the research location shows optimal values and was very suitable for soybean plant growth and the recommendation of nutrient application to the soil and plants. The assessment of soil Cation Exchange Capacity (CEC) could also serve as a reference for determining nutrient requirements in the land. The high or low value of soil CEC was fundamentally determined by the physical properties of the soil, such as texture and the organic matter content of the soil layer (Syachroni, 2019).

Nutrient Available (na)

Nutrient retention includes N-Total, P_2O_5, and K_2O. The results of the analysis were in Table 6.

Table 6. The results of the nutrient available analysis

Sample	N-Total (%)	P_2O_5 (mg 100/g)	K_2O (mg 100/g)
1	0.33 [M]	3.29 [M]	12.07 [VL]
2	0.24 [M]	4.25 [H]	12.07 [VL]
3	0.14 [L]	3.39 [M]	9.05 [VL]
4	0.16 [L]	4.68 [H]	12.07 [VL]
5	0.10 [L]	2.86 [M]	12.07 [VL]
6	0.35 [M]	3.69 [M]	12.07 [VL]
7	0.28 [M]	4.62 [H]	15.09 [L]

Note: [VL]= Very low; [L]=,Low; [M]=,Moderate; [H]=,High
Sources : Technical guidelines edition 3: Chemical analysis of soil, plants, water and fertilizers. (Kementerian Pertanian Republik Indonesia, 2023)

Essential nutrients such as N, P, and K were very important for soil and plants. The presence of these nutrients in sufficient amounts will increase the productivity of soybean crops. nitrogen nutrients have low to moderate criteria. in this case the availability of N was still sufficient to meet the nitrogen needs of plants. While the P nutrient was also available in sufficient conditions in the soil. The availability of Nitrogen and phosphorus nutrients in the soil will support the plant growth process, namely in plant height, roots, and soybean plant weight.

The research location had a limiting factor, namely the deficiency of K_2O nutrients in the soil. The low potassium content in the soil was usually caused by soil pH, leaching of potassium by water, excessive absorption of potassium by plants, and the insufficient amount of potassium fertilizer provided by farmers, which does not meet the soil's potassium fertilizer needs. Furthermore, according to (Masganti et al., 2023), the factor causing the low levels of these elements in the soil was the farmers habit of not returning rice straw after harvest. To address this limiting factor, potassium fertilizer could be applied in sufficient amounts to support soybean productivity in tidal lowland. The fertilizer that was often given by farmers on the land was KCL fertilizer. High soybean yields could be influenced by the availability of sufficient soil nutrients. The application of KCl fertilizer at a dose of 99.28 kg/ha on tidal soil could produce up to 1.18 tons/ha of soybeans (Mustaanullah et al., 2022).

Actual Land Suitability

The assessment of actual land suitability was the evaluation of land suitability before any input of additions or improvements. The assessment of actual land suitability was in Tables 7 and 8.

Table 7. Assessment of actual land suitability (Samples 1-4)

Land Characteristic	Actual Land Suitability							
	Sample 1		Sample 2		Sample 3		Sample 4	
	Result	Suitability Class	Result	Suitability Class	Result	Suitability Class	Result	Suitability Class
Temperature (tc)								
Temperature Average (˚C)	28	S2	28	S2	28	S2	28	S2
Water Availability (wa)								
Rainfall (mm)	2802	S3	2802	S3	2802	S2	2802	S3
Root Media (rc)								
Texture	SCL	S1	SCL	S1	SC	S3	SCL	S1
Soil Depth (cm)	>60	S1	>60	S1	>60	S1	>60	S1
Nutrient retention (nr)								
CEC soil (cmol)	19	S1	24.46	S1	21.75	S1	24.46	S1
pH H_2O	4.00	S3	4.28	S3	3.53	S3	3.59	S3
C-Organik (%)	2.84	S1	2.18	S1	1.98	S1	2.33	S1
Nutrients Available (na)								
N-Total (%)	0.33	S1	0.24	S1	0.14	S2	0.16	S2
P_2O_5 (mg/100 g)	3.29	S2	4.25	S1	3.39	S2	4.68	S1
K_2O (mg/100 g)	12.07	S3	12.07	S3	9.05	S3	12.07	S3
Sulfidic Hazards (xs)								
Sulfidic Depth (cm)	43	S3	45	S3	55	S3	65	S3
Danger of Flooding (fh)								
Flood Depth	-	S1	-	S1	-	S1	-	-
Actual Suitability	S3-wa,nr,na,xs		S3-wa,nr,na,xs		S3-wa,rc,nr,na,xs		S3-wa,nr,na,xs	

Note: S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, SCL: Sandy clay loam, SC: Sandy clay

Table 8. Assessment of actual land suitability (Samples 5-7)

Land Characterisctic	Actual Land Suitability					
	Sample 5		Sample 6		Sample 7	
	Result	Suitability Class	Result	Suitability Class	Result	Suitability Class
Temperature (tc)						
Temperature Average (˚C)	28	S2	28	S2	28	S2
Water Availability (wa)						
Rainfall (mm)	2802	S3	2802	S3	2802	S2
Root Media (rc)						
Texture	SCL	S1	SCL	S1	SCL	S3
Soil Depth (cm)	>60	S1	>60	S1	>60	S1
Nutrient Retention (nr)						
CEC Soil (cmol)	19	S1	16.31	S1	24.46	S1
Ph H_2O	3.77	S3	3.25	S3	4.10	S3
C-Organik (%)	1.67	S1	3.27	S1	2.22	S1
Nutrient Available (na)						
N-Total (%)	0.10	S2	0.35	S1	0.28	S1
P_2O_5 (mg/100 g)	2.86	S2	3.69	S2	4.62	S1
K_2O (mg/100 g)	12.07	S3	12.07	S3	15.09	S3
Sulfidic Hazards (xs)						
Sulfidic Depth (cm)	60	S3	40	S3	40	S3
Danger of Flooding (fh)						
Flood Depth	-	S1	-	S1	-	S1
Actual Suitability	S3-wa,nr,na,xs		S3-wa,nr,na,xs		S3-wa,nr,na,xs	

Note: S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, SCL: Sandy clay loam

From the results of the actual land suitability class grouping in Table 7 and Table 8, it could be seen that each average point had a different suitability class based on its limiting factors. At sample 1, 2, 4, 5, 6, and 7, the actual land suitability classes were S3-wa, nr, na, xs with limiting factors of Rainfall, Soil pH, K2O, and Pyrite Depth. Meanwhile, at the sample point 3, the actual land suitability class was S3 rc, nr, na, xs with limiting factors of rainfall, texture, soil pH, K2O, and pyrite depth. The limiting factors above were the dominant limiting factors and fall into the category of Marginally Suitable Land Class (S3).

The limiting factors S3-Rainfall (wa), nutrient retention (nr), and available nutrients (na) were limiting factors that could still be addressed and improved through inputs that will be provided later. The limiting factor of the root media (rc) was a permanent limiting factor that was quite difficult to improve and will also take a considerable amount of time, but improvements could still be made according to its limiting factors. The next main limiting factor was the pyrite layer (FeS_2), which poses a major obstacle in utilizing tidal lands with acid sulfate soil characteristics to support agricultural productivity. In this case, S3-xs becomes a limiting factor that could be self-repaired by the farmers or requires intervention from the government. The problem of pyrite (FeS2) arises from groundwater levels and waterlogging, particularly during the rainy season, leading to oxidation of the pyrite layer with the onset of the dry season. Acid sulfate tidal swamplands typically exhibit elevated aluminum (Al) solubility. This results from the elevated soil acidity, which could enhance aluminum solubility. The form of aluminum absorbed by plant roots, which could be toxic, varies across different plant species and their respective portions (Alwi et al., 2021). This was undoubtedly linked to farmers water management in the channels and tertiary plots where they raise crops. Pirit could be addressed by managing the groundwater level that must be maintained by the farmers. Pirit could be mitigated by regulating the groundwater levels that farmers must sustain.

Potential Land Suitability

The assessment of potential land suitability was the evaluation of land suitability that will be achieved after the addition or improvement inputs. The assessment of actual land suitability was in Table 9.

Table 9. Potential land suitability

Sample	Actual Land Suitability	Input	Repair Level	Potential Suitability
1, 2, 4, 5, 6, 7	S3-wa, nr, na	Irrigation and drainage, Liming, Fertilization	++	S1-wa, nr, na
	S3-xs	Groundwater level control	+	S2-xs
3	S3-wa, nr, na	Irrigation and drainage, Liming, Fertilization	++	S1-wa, nr, na
	S3-rc	-	-	S3-rc
	S3-xs	Groundwater level control	+	S2-xs
Potential Suitability				S2-xs S3-rc

Note,: (++) *Increase of two levels in land suitability class,* (+) *Increase of one level in land suitability class,* wa= Water availability; rc= Root media; nr= Nutrient retention; na= Nutrient available; xs= Sulfidic hazards; : S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable. Sources: Technical guidelines for land evaluation for strategic agricultural commodities at a semi-detailed level, scale 1:50,000 (Wahyunto et al., 2016)

The potential suitability class for each soil sample was determined, and it was found that samples 1, 2, 4, 5, and 6 have land suitability classes S3-wa, nr, na, and xs with limiting factors of rainfall, soil pH, K2O, and sulfidic depth. In sample 3, the land suitability class was S3-rc, wa, nr, na, xs with limiting factors of rainfall, texture, soil pH, K_2O, and sulfidic depth. In S3-nr, na could still be addressed or managed by providing inputs such as liming, adding organic soil materials, and applying KCl fertilizer to the soil with high-level improvements (++) so that it becomes a potential land suitability class S1 (very suitable).

In the S3-xs suitability class, it could be upgraded by one level to the land suitability class (+), thus becoming the Fairly Suitable (S2) suitability class. The issue of sulfide depth could be controlled in stages, starting with a moderate level by managing the groundwater table to be lowered below the root zone, specifically at a depth of 40-50 cm below the soil surface (Rahajeng et al., 2021). Generally, pyrite was not harmful when the land was wet or flooded, but pyrite becomes very dangerous for plants when it oxidizes with air (Imanudin et al., 2024). Because of this, the control of pyrite was closely related to the control and management of groundwater levels in channels and fields.

The issue of root media in the form of soil texture categorized as S3-rc cannot be quickly improved like the problem of the presence of a pyrite layer. Root media problems could be addressed gradually, including soil management, the addition of organic soil materials, soil conservation with minimal soil management, and irrigation system management on the land (Ding et al., 2023). With an integrated and sustainable approach, soil conditions with texture limitations such as category S3-rc could be gradually improved to support long-term agricultural productivity.

DISCUSSION

The results of the land evaluation indicate that the land suitability class for soybean cultivation at the study site is predominantly marginally suitable (S3-wa, nr, na, xs), due to several limiting factors, including water availability, nutrient retention, available nutrients, and the presence of sulfide hazards. These findings are consistent with those of Imanudin et al. (2023), who reported that tidal lowlands—particularly those characterized as acid sulfate soils—are constrained by low inherent fertility, which can significantly affect crop productivity.

The issue of pyrite layers and the danger of stagnant water stress on tidal wetlands often attract attention in the development of agriculture in this area. During the field research, there was no flooding on the land, but the pyrite layer was shallow, and in the dry land conditions, the pyrite was oxidized. According to Imanudin et al. (2021a) long-term oxidation of the pyrite layer causes the soil to become very acidic, and if left unaddressed, the land will become unsuitable especially for soybean cultivation. The research was conducted (Liu et al., 2025) concluded that water plays an important role as a reaction medium in the oxidation process, with infiltration rate directly affecting the oxidation rate. Soil and water management is essential to address the issue of pyrite. Therefore, pyrite can be addressed by managing the groundwater level that must be maintained by farmers through tertiary channels. The channels that are built will later function to regulate water supply during high and low tides, so that the groundwater level can be controlled properly and reduce the risk of flooding during the rainy season while also preventing the land from experiencing drought during the dry season (Imanudin et al., 2021b). According to (Imanudin et al., (2021c) the drainage control system in channels, especially tertiary channels, will prevent the oxidation of pyrite, which can be harmful to soil and plants.

The soybean cultivation pattern in the tidal zone is influenced by the planting system and climatic conditions. According to (Mawardi & Khairullah, 2022) that water management in agricultural development inside tidal swampland must consider the kind of overflow, land typology, and land attributes. Tidal land is cultivated in two distinct seasons. The first from November to April and the second from May to October. During the initial planting season, farmers cultivate rice as the fields are inundated with substantial rains. Subsequently, in the second planting season commencing in May, farmers initiate the cultivation of secondary crops, including soybeans.

Planting soybeans in first planting season, which is between November and April along with rice, will face limiting factors such as flooding due to climate change, namely tidal water and excessive rainfall (Brito et al., 2023). If cultivated continually, soybean plants would be flooded, producing serious concerns such as root rot. Micro-water control is essential for soybean cultivation in tidal regions. The canals are constructed with a width of 30 cm and a depth of approximately 20 cm, situated between plots or beds that are roughly 4 m broad. This conduit will enable the ingress of tidal water into the land during the dry season. Next, The water in the beds must be sustained from the initiation of planting till harvest. After the tide enters the channel, the beds can be sprayed with a systemic herbicide two weeks before planting.

CONCLUSION

The actual land suitability for soybeans indicates that the land has suitability criteria of S3-wa, nr, na, and S3-xs. Meanwhile, the potential land suitability class for soybeans is S2-xs with the limiting factor of sulfide hazard. Land improvement inputs that can be implemented to address the issue of sulfide or pyrite hazards include controlling the groundwater level regulated through tertiary channels, while other limiting factors can be mitigated by adding inputs such as lime application, organic matter addition, and fertilization to minimize soil acidity and nutrient retention limiting factors.

An integrated water management system and proper planting schedule are very important to implement in soybean cultivation on tidal lowland, as soybean plants are not resistant to flooding stress and pyrite toxicity. Therefore, farmers should close the water management gates on the tertiary channels during the soybean planting season. Additionally, soil management practices such as creating bunds or ridges can also be implemented to address flooding stress and pyrite oxidation in the soil.

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