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Land suitability assessment to achieve optimal field rice yield

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Abstract
Shifting cultivation of dryland rice is still practiced by indigenous Kalimantan people to fulfill their own needs for rice. The selected locations are mainly young secondary forest land cover with a fallow period of 10-15 years for easier work and higher biomass. The stage of shifting cultivation that most determines the ease of subsequent activities, growth and yield is the amount of biomass burned (>70%) to ash, except for parts of trees >15cm in diameter. Ash contains available macro and micro nutrients that can increase nutrient retention (nr), namely CEC, base saturation and pH and available nutrients (na) N, P and K. Assessment of land suitability to the requirements of growing field rice with the matching method, that the minimum land characteristics are the heaviest constraints that determine the class and sub-class land suitability. The evaluation results obtained actual land suitability sub-class S3nr,na, the heaviest limiting factors of nutrient retention and nutrient availability. Improvement of biomass ash after land burning occurs naturally starting with rain. Improvement of limiting factors is naturally limited, farmers must add N and P nutrients from Urea and Super Phosphate-36 (SP-36) fertilizers at doses of N 25-40 $kg.ha^{-1}$ and P 30-50 $kg.ha^{-1}$. Fertilizers are applied by sowing at 21 days of age and 45 days of age at a dose of 50% each. After the improvement efforts were made, the growth of field rice was better so that production increased. The sub-class of suitability increased one level to S2eh,nr, the limiting factors are slope class (eh) and nr.

Keywords: Land suitability, biomass burning, field rice production

Introduction

Dryland rice cultivation in shifting cultivation systems, also known as gilir balik, is still practiced by indigenous Kalimantan people to meet their own needs for rice (Palupi *et al.*, 2023) [1]. The location chosen is mainly forest land cover with a fallow period of 10-15 years with consideration of soil fertility has recovered. In addition to the fallow period, location selection considerations are mainly relatively close to the place of residence and easy to reach. The main factor of the longer fallow period was chosen due to hereditary experience, namely easier to work, lighter management, more fertile if biomass burning is high so that crop yields increase.

A more objective assessment for shifting cultivation activities based on scientific methods needs to be applied with the land evaluation method, which has only been used for wet rice activities. The application of land evaluation to assess the suitability class of land characteristics for paddy fields resulted in the identification of the actual suitability class and the heaviest limiting factor of land characteristics. Optimizing the results, improvements are made to the lowest scale limiting factors that are possible and can be done by traditional farmers with technological inputs such as fertilization (Darma *et al.*, 2023; Palupi *et al.*, 2024) [2, 3].

In the process and stages of activities, some limiting factors may naturally change to become lighter or no longer the heaviest limiting factor. High levels of biomass burning (>70%) to ash will improve by increasing available macro and micro nutrients and reducing surface soil acidity (Darma and Fahrunsyah, 2022) [4]. Land characteristics that can be improved naturally by the presence of burnt ash are nutrient retention and available nutrients. The application of granular inorganic fertilizers such as urea and SP-36 by sowing needs to be done to increase soil fertility so that productivity increases from usual, the ultimate goal of their main food sufficiency of rice is met.

Methods

Location and Materials

The study location was in Hambau Village, Kembang Janggut District, Kutai Kartanegara Regency, East Kalimantan Province. Time of field activities and soil sampling in April 2024. Field equipment GPS, pH stick, soil drill, clinometer, plastic bags, markers, machetes and others refer to Wahyunto *et al*. (2020) and Darma (2022) [5, 6]. The material tools operated in this study include administrative map of Kutai Kertanegara Regency, earth shape map of Indonesia, laboratory equipment, and chemicals for soil analysis.

Data Collection

Land characteristics include annual average temperature, rainfall, air humidity, drainage, texture, coarse material, effective depth, CEC, base saturation, pH, organic C, total N, P_2O_5, K_2O, salinity, alkalinity, slope, surface rocks, rock outcrops, landslide hazard and erosion hazard (Ritung *et al*., 2011) [7]. Field survey to observe some of the physical characteristics of the land that were not analyzed in the laboratory and take soil samples. Soil samples were taken compositely at a depth of 0-20cm (Purwanto *et al*., 2014) [8]. Soil samples were analyzed at the Soil Laboratory of the Faculty of Agriculture, Universitas Mulawarman, including chemical properties and physical properties with parameters in accordance with the criteria for land characteristics. Climatic data on rainfall and temperature (BPS-Statistics Kutai Kartanegara, 2024) [9]. Criteria for the requirements of field rice land characteristics (Wahyunto *et al*., 2016) [10].

Data Analysis

Land characteristics such as climate, physico-chemical and environment are matched with the requirements of growing field rice to obtain the level of suitability. Land suitability class is divided into S1 (highly suitable) land with mild constraints without additional input, S2 (moderately suitable) land with moderate constraints require moderate additional input and S3 (marginally suitable) land with severe constraints require additional input more than S2 (Food and Agriculture Organization, 1976) [11]. Determination of land suitability classes by matching between land characteristic data obtained against specific land use requirements (Djaenudin *et al*., 2011; Ritung *et al*., 2011) [12, 13]. Land characteristic requirements and land suitability classes for field rice (Ritung *et al*., 2011) [13]. This results in the actual suitability class (A) and its limiting factors. Improvement with low and medium levels of management so as to obtain a potential suitability class (P).

Results and Discussion

Land Characteristics

Climatic characteristics that affect the growth and production of field rice are temperature, rainfall and air humidity, the three factors that cannot be changed in the field. Based on data for 10 years, the average daily temperature is 29.0 °C with variations between the lowest and highest temperatures between 6-7 °C and 84.0% air humidity. Wet months (>200 mm/month) 5 months a year, classification (Madani and Wahid, 2022) [14]. From field observations the land surface is flat to undulating with slopes of 8-15%. Drainage includes a class of slightly good to good which is characterized by homogeneous soil color, no mottling (Rust) is found which indicates smooth groundwater movement (Ritung *et al*., 2007) [15]. Clayey loam (CL) soil texture is classified as a rather fine class, deep soil depth (>75 cm) and little coarse material (<15%) consisting of gravel or gravel. The findings of chemical analysis of composite soil samples in Table 1.

Table 1: Analytical of Composite Soil Samples

Soil Chemistry	Value	Criteria
pH (H_2O)	4.82	Acid
C-organic (%)	0.62	Very Low
CEC (cmol $_{(+)}$ kg^{-1})	14.68	Low
Base Saturation (%)	19.45	Very Low
Al saturation (%)	38.28	High
N-total (%)	0.14	Low
P_2O_5 (ppm)	6.83	Low
K_2O (ppm)	25.72	Medium
Soil Physical (Texture)	(%)	-
Clay	38.4	C
Loam	35.8	L
Sand	25.8	S
Texture class	Clay Loam	CL

The soil pH value is 4.82 (Acidic), basic cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) do not dominate in the soil solution and soil colloidal surface, but are dominated by acidic cations (Al^{+3} and H^{+}) so that base saturation is only 19.45% (Very low) and Al saturation is 38.28% (High). Acidic soil illustrates that the availability of P nutrients for plants is low because it is bound by Al^{+3}. P nutrient availability will increase if soil acidity is reduced. The limit of Al solubility and maximum P binding is around pH 5.5 then Al begins to precipitate and P begins to be released until the maximum available around pH 6.5-7 (Penn and Camberato, 2019) [16]. On the other hand, the binding of P by Fe occurs at pH <4.5 due to the high solubility of (Li and Jhonson, 2016) [17].

Land Suitability Assessment

Actual land suitability is the level of natural suitability of a land for the use of certain agricultural commodities without human intervention on its land characteristics (see Table 2). The identification of actual land suitability (A) that the location of the fields for growing rice actually has the main or heaviest limiting factor is nutrient retention (nr), namely acidity of acidic planting (pH 4.82), low organic matter content and base saturation which indicates a general lack of metal-type nutrients such as Ca, Mg, K and Na. The factor of low nutrient retention or the minimum determines the land suitability class S3 sub-class S3nr. Based on Liebig's law (1840) in Mustaqim (2018) [18], if connected to agriculture that the most determining factor is the minimum amount that determines the growth and yield of plants. The heaviest limiting factor is the main concern for land management of field rice plants for better growth so that productivity can be increased.

Table 2: Land Suitability Assessment for Paddy Fields

Land Characteristics	Data	Actual Suitability Score and Class (A)		Improve-ment Efforts	Potential Suitability Score and Class (P)	
Temperature (tc)			S1			S1
Average temperature (°C)	29.0	S1			S1	
Water availability (wa)			S1			S1
Agroclimatic zone (Oldeman)	C2, C3	S1			S1	
Humidity (%)	84.0	S1			S1	
Rooting medium (rc)			S1			S1
Drainage	Somewhat good	S1			S1	
Texture	CL	S1			S1	
Coarse material (%)	< 15	S1			S1	
Soil depth (cm)	> 75	S1			S1	
Nutrient retention (nr)			S3	+		S2
Soil CEC (cmol $_{(+)}$ kg^{-1})	14.68	S2			S2	
Base saturation (%)	19.45	S3			S2	
pH H_2O	4.82	S3			S2	
C-organik (%)	0.62	S3			S2	
Nutrients Available (na)			S3	+		S2
N total (%)	0.14	S2			S1	
P_2O_5 (mg/100 g)	6.83	S3			S2	
K_2O (mg/100 g)	25.72	S1			S1	
Toxicity (xc)			S1			S1
Salinity (dS/m)	< 2	S1			S1	
Sodicity (xn)			S1			S1
Alkalinity /ESP (%)	1.55	S1			S1	
Erosion hazard (eh)			S2			S2
Slopes (%)	8-15	S2			S2	
Erosion hazard	Light-Moderate	S2			S2	
Land preparation (lp)			S1			S1
Rocks on the surface (%)	< 5	S1			S1	
Rock outcrops (%)	< 5	S1			S1	
Assessment result		Actual	S3nr,na		Potential	S2eh,nr

Description: +Improvement can be done one level higher (S3 to S2).

Efforts to increase productivity with improvements to the heaviest limiting factor of nutrient retention results in potential suitability (P). Improvements that can be made by farmers indirectly and directly. Indirectly, dry slash and cut biomass will be burned. Good biomass burning up to the level of incineration Ismail (2005) [19] will produce maximum ash and charcoal, the ash from combustion is the unburned part of the biomass, almost completely metal macro-nutrients (Ca, Mg, K, and Na) and micro-nutrients and macro-nutrient P (Symanowicz *et al*., 2018) [20]. If there is rain it produces a strong base, the alkaline nature will reduce the acidity of the soil. Metal nutrients from ash and hydroxyl ions (OH^-) will enter the soil solution through soil pores with rainwater media as metal ions that are exchanged with soil colids to increase base saturation and soil CEC, while hydroxyl ions interact with hydrogen ions (H^+) to reduce soil acidity so that the soil pH value rises. The increase in soil pH above the original 4.82 decreases the solubility of Al thereby increasing the availability of P in the form of $H_2PO_4^-$ and HPO_4^{-2} for plants. Phosphate ions are absorbed by plant roots from the soil solution (Singh and Schulze, 2015) [21]. Nutrient P is a major part of Adenosine Triphosphate (ATP) as a store and transfer of energy in plants used for photosynthesis, protein synthesis, translocation and absorption of nutrients and respiration (Plaxton and Tran, 2011) [22]. The role of P nutrients is related to flower formation and seed development, so if fulfilled, it increases the quantity and quality of fruit (Khan *et al*., 2023; Osman *et al*., 2014) [23, 24].

Changes in soil chemical properties were mainly in the rhizosphere area of field rice plants up to about 20 cm deep (Thepbandit and Athinuwa, 2024; Ferrarezi *et al*., 2022) [25, 26]. Clayey loam (CL) soil texture has predominantly medium and fine pores (Feiza *et al*., 2015) [27]. A small portion of unburned and incompletely burned biomass will become soil organic matter, thus increasing organic matter content. Indirectly, land burning increases nutrient retention so that it is no longer a major limitation that can increase the original suitability class S3 to S2 sub-class S2eh,nr. The main limiting factor that is difficult to change the slope affects the erosion caused by the mild to moderate class, especially after burning biomass until the field rice is about 3 months old (Deng *et al*., 2020) [28].

A direct remedy is to sprinkle soil acidity-reducing materials such as agricultural lime to reduce soil acidity and increase base saturation. The type of agricultural lime used contains the main nutrient Ca (Calcite) or which contains the main nutrient Mg (Dolomite). Addition of organic matter in the form of compost to increase organic carbon levels in the soil. The practice of planting field rice of indigenous Kalimantan tribes does not recognize the addition of soil conditioners with liming and organic matter, improving the nutrient retention of field soil is done indirectly, namely the effect of the results of burning biomass that has dried (Gay-des-Combes *et al*., 2017) [29]. The Indonesian government has issued a policy as a solution to the problem that has been going on for about fifty years by legalizing communities to clear land by burning for shifting cultivation activities on their own land of 2 ha per family head by making firebreaks around the land to be burned as an effort to prevent forest and land fires (Rambe *et al*., 2024) [30]. This middle way is so that indigenous peoples can meet their basic needs but the preservation of nature and the environment is maintained, in practice the fallow period affects the recovery of macro nutrients and soil organic matter as a determinant of soil fertility (Mukul *et al*., 2022) [31].

Nutrients play a major role in the growth of the vegetative and generative periods of rice plants, including field rice (Effendi *et al*., 2023; Winarso *et al*., 2022) [32, 33]. Available nutrients (na) need to be added, especially macro-nutrients N and P because the low status will be a limiter when other factors are increased although the potential land suitability class (P) is not changed by the heaviest limiting factor, but can improve growth and yield. The application of N fertilizers to low N soils reacts quickly to spur better vegetative growth of rice plants, while the application of slower reacting P fertilizers is more intended to spur further growth of the vegetative phase that previously absorbed the diminishing natural soil P nutrients to be sufficient and ensure a better generative phase (Fernandus, 2023) [34]. Application of granular N and P fertilizers is the best choice in a practical way, namely spread evenly while walking when the rice is three weeks old or about 21 days and 45-60 days old, it is easier and faster so that local farmers want to do it (Meilani *et al*., 2023; Mulyaningsih *et al*., 2015; Prabukesuma *et al*., 2015) [35, 36, 37]. As an illustration, the dose of N is 25-40 $kg.ha^{-1}$ and P is 30-50 $kg.\ ha^{-1}$, the source of fertilizer includes N from urea fertilizer and P from SP-36 fertilizer. The first and second application of N and P fertilizers are each 50% of the dose. Providing additional fertilizer will affect good growth in the vegetative and generative phases so that productivity increases from usual.

Conclusion

The actual land suitability class for field rice studied is marginally suitable (S3), the heaviest limiting factors are nutrient retention (nr) and nutrient availability (na) sub suitability class S3nr,na. The growth of field rice is less than optimal due to the heaviest limiting factor of nutrient retention (nr), namely low base saturation, acid soil and very low organic matter. Another limiting factor is nutrient availability (na), especially low available P nutrients. Biomass combustibility is high to the extent that incineration produces maximum ash. The ash consists of macro-nutrients especially base metals (Ca, Mg, K, Na) and P as well as micro-nutrients, which are available for field rice. It naturally ameliorates limiting factors, increasing nutrient retention and nutrient availability. Ash nutrient supply is uncertain, affected by biomass dryness during burning. Additional N and P nutrient fertilization is required to achieve optimum grain yield of field rice.

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