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Establishment of Soil Quality Critical Limits and Yield Prediction of Two *Musa* Cultivars in *Bambusa tulda* Assisted Jhum and Fallow Systems of Northeastern India

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***Abstract*:** Shifting cultivation (Jhum) landscapes of Northeast India are increasingly affected by shortened fallow cycles, resulting in declining soil fertility and reduced crop productivity. Developing restoration strategies that improve soil quality while sustaining livelihoods is therefore critical for the long-term sustainability of upland agro-ecosystems in the region. The present work investigates the benefits of integrating *Bambusa tulda* and fallow duration in restoring soil productivity and improving banana performance in Jhum and fallow systems of Nagaland, Northeast India. Four land-use conditions—active Jhum land (JL), 3-year fallow (AJL3), bamboo-assisted fallow (AJLB), and 12-year fallow (AJL12)—were assessed using soil quality indicators, critical-limit analysis, and agronomic evaluation of two Musa cultivars (Atsu Mungo and Aot Mungo). The findings displayed higher soil organic carbon, nutrient availability, clay content, and moisture at AJLB and AJL12, which corresponded with superior vegetative growth, reduced crop cycle duration, and higher bunch weight and relative yield compared with JL and AJL3. Critical-limit categorization placed most soil indicators of AJLB and AJL12 within the adequate range, while JL and AJL3 remained largely moderate. Stepwise regression depicted that soil moisture and clay content were the strongest predictors of yield across cultivars. This study provides the first critical-limit framework linking soil quality indicators with banana productivity in bamboo-assisted Jhum systems of Northeast India, demonstrating that bamboo-based fallow management can accelerate soil recovery and enhance crop productivity in degraded shifting-cultivation landscapes.

***Keywords*:** Critical limits, *Bambusa tulda,* Banana yield prediction, Jhum.

1. INTRODUCTION

In Northeast India, shifting cultivation (Jhum)-involving slashing, burning, cultivation and fallow-has historically sustained rural livelihoods (Tripathi et al., 2017). However, population pressure has shortened fallow cycles, driving unsustainable practices that alter soil structure, deplete organic matter and suppress microbial activity, ultimately degrading soil quality (Mishra et al., 2021; Semy et al., 2022). In contrast, the introduction of bamboo (*Bambusa tulda* Roxb.) systems is noted for stabilising soils, curbing erosion and runoff, and enhancing nutrient status and overall soil health (Shanmughavel et al., 2000). Given India's extensive bamboo cover and rapid growth rates, bamboo offers a promising nature-based route for restoring degraded jhum lands while contributing to carbon sequestration (Kaushal et al., 2021). Demand for bamboo across dietary, nutraceutical, fuel and timber sectors further strengthens its socio-economic appeal in the Northeast (Basumatary et al., 2017).

Defining locally relevant soil indicators and their critical limits, i.e., concentrations associated with achieving ~80–90% of attainable yield, facilitates interpretation of soil function across land uses (Biswas et al., 2017). In Nagaland, banana is a key livelihood crop, yet hilly terrain, erosion risk and variable water supply under Jhum landscapes hinder productivity (Nyamamba et al., 2020; Solo and Kikhi 2021). Evidence suggests that shortened fallows reduce productivity across shifting-cultivation systems (Rahman et al., 2014). Bamboo's restorative effects are documented, but potential to enhance agronomic performance on degraded Jhum lands—particularly for banana—remains underexplored in the region (Shilla and Mir 2017; Kaushal et

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al., 2021). Therefore, the present study was conducted to evaluate agronomic performance of selected *Musa* cultivars under experimental conditions and defined critical limits for key soil indicators to support monitoring and management in Nagaland, North-East India.

2. MATERIALS AND METHODS

2.1. Description of the Study Site

The experimental sites (Figure 1) were selected under Mokokchung District, Nagaland, India ($94^0 32'39''$E and $26^0 13'44''$N, 1093m amsl), which has a humid subtropical climate and ~2,500 mm annual rainfall (Longchar et al., 2023). Shifting cultivation is the main form of agriculture for the indigenous inhabitants of the region.

2.2. Experimental design and treatment

Four sites with contrasting fallow periods were selected to test the effect of fallow and *Bambusa tulda* Roxb. on productivity (Table 1). Two *Musa* cultivars common in the region—Aot Mungo (Figure 2) and Atsu Mungo (Figure 3) —were used, with Mokokchung being the state's second-largest banana producer (Murry and Das 2019). Mother plants were inspected for the presence of pests and diseases before sucker collection (Tumuhimbise and Talengera 2018). Uniform suckers from a single farm received hot-water treatment to reduce weevil and nematode infestation (Uwimana et al., 2020). At each site, eight suckers per cultivar (16 per site; 64 total) were planted at 5 × 5 m

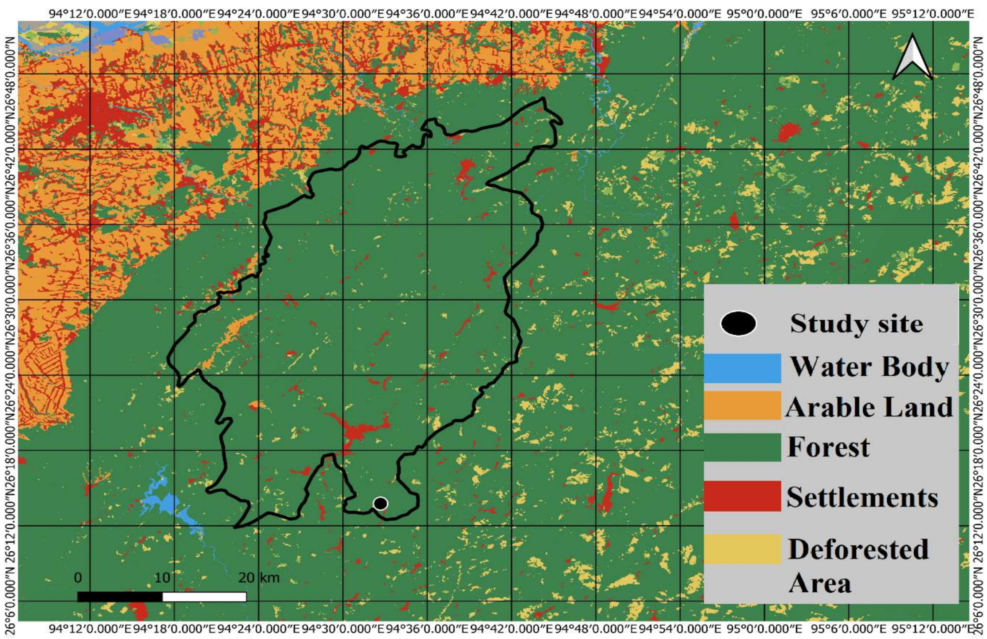

Figure 1. Land use map of study area under Mokokchung district, Nagaland, North-East India (QGIS 4.0)

Table 1. Description of the experimental sites

Site	Cultivation period	Fallow period	Vegetation
Jhum land (JL)	3 years	Not available	3rd cycle of cassava monocropping
Abandoned Jhum land 3 (AJL3)	3 years	3rd year of fallow	*Ageratum* conyzoides, *Eupatorium* sp., *Erigeron Canadensis, Erechtites* sp., *Ischaemum muticum*, *Galinsoga* sp., *Macaranga* sp., *Mucuna puriens, Mikiania scadens, Poa trivialis, Pteris vittata, Sonchus* sp., *Thysanolaena maxima,* and *Thysanolaena* sp.
Abandoned Jhum land bamboo (AJLB)	3 years	3rd year of fallow	Mainly composed of *Bambusa tulda* with other associated species such as *Angiopteris evecta, Ageratum conyzoides, Artemisia vulagris, Eupatorium* sp., *Spatholobus* sp., *Thysanolaena maxima, Macaranga peltata, Persea fructifera*
Abandoned Jhum land 12 (AJL12)	3 years	12th year of fallow	*Albizia chinensis*, *Angiopteris* sp., *Azadirachta indica*, *Macaranga peltata*, *Phyllanthus emblica*, *Polygonum molle*, *Persea fructifera*, *Sonchus* sp., *Schima wallichi*, *Thysanolaena maxima* and *Terminalia myriocarpa*.

spacing. No fertilizers or chemicals were applied post-planting, and all sites were monitored weekly through the first crop cycle (planting to harvest).

2.3. Soil Analysis

Soil samples (0-30 cm) were collected seasonally from the study sites from March (2020) till the completion of the first plant cycle (i.e., planting to harvest). Bulk density and soil moisture were determined by utilizing fresh soil. All other soil tests were performed by utilizing air-dried samples sieved through a 2-mm nylon sieve (Table 2). All tests were performed in triplicates and expressed as mean ± standard deviation.

2.4. Agronomic Performance of the *Musa* Cultivars

Suitable agronomic traits were selected from the method proposed by Uwimana et al. (2020), consisting of three broad categories, namely: Vegetative, maturity, and fruit yield (Table 3)

The expected fruit yield (Eq. 1) was reported as per Hauser and Van Asten (2010), and the Relative yield (Eq. 2) was estimated as per Biswas et al. (2017):

$$\text{Expected fruit yield} = \frac{\text{BW} \times 10{,}000 \times 365}{\text{Spacing} \times \text{PC} \times 1000} \quad \text{..... (1)}$$

$$\text{Relative yield (\%)} = \frac{\text{Yield of a sampling plot}}{\text{Maximum yield of a sampling plot}} \times 100$$

2.5. Critical Limits of Soil Quality Indicators of the Selected *Musa* Cultivars

It is defined as the optimum values required for the normal functioning of soil and its health for sustainable crop production (Biswas et al., 2017). This is obtained by running a linear regression between soil parameters and relative yield for obtaining the 40% and 80% of the maximum

Table 2. Soil analysis protocol

Soil parameters	Methods
pH	Digital pH meter
Electrical conductivity (EC)	EC meter
Soil moisture	Gravimetric method (Misra, 1968)
Clay content	Pipette method (Piper, 1942)
Bulk density (BD)	Core sampler method (Allen, 1989)
Soil organic carbon (SOC)	Walkley and Black method (1934)
Available nitrogen (N)	Kjeldahl method (1883)
Available phosphorus (P)	Bray's no. 1 extract method (Bray and Kurtz 1945)
Available potassium (K)	Photometric method (Trivedy and Goel 1986)
Cation exchange capacity (CEC)	Bower et al. (1952)
Total Nitrogen (TN)	Kjeldahl (1883)

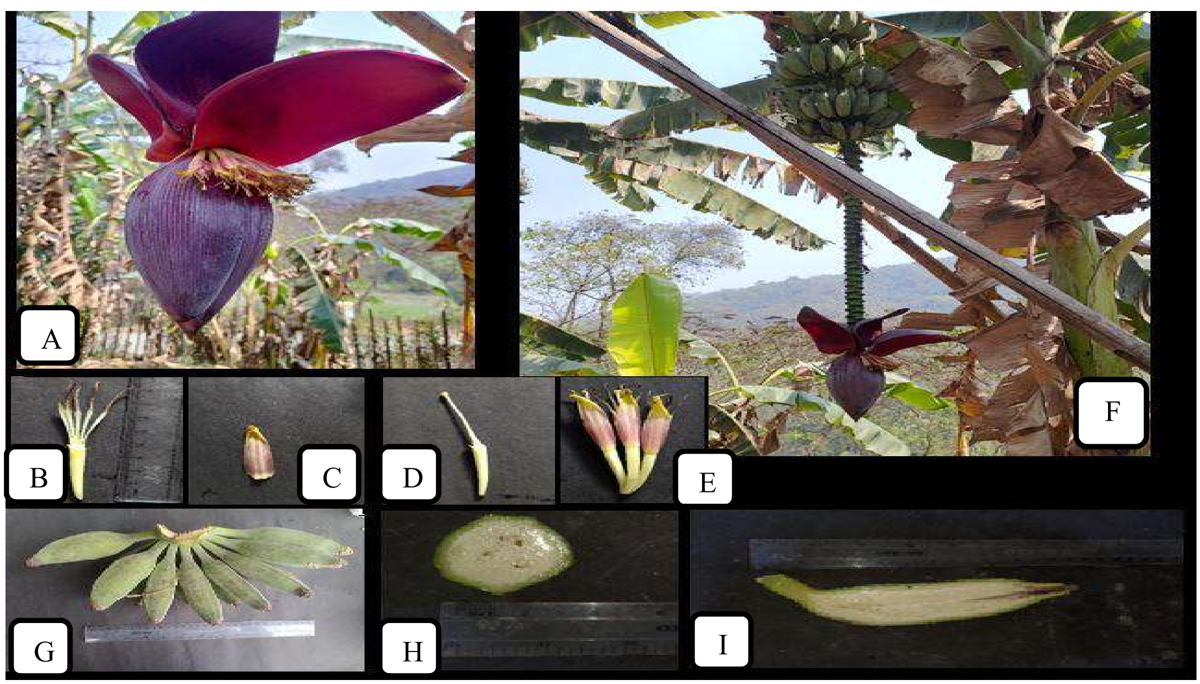

Figure 2. *Musa* sp 1: Aot Mungo (Ao Naga) with various floral parts in picture. A: Banana inflorescence. B: Stamens. C: Tepal. D: Style and stigma. E: Male Flowers. F: Banana flowering. G: Banana bunch. H: Transverse section of fruit. I: Longitudinal section of fruit

possible yield. For this equation, the relative yield (X) = 40 and 80 are recorded and the corresponding value of soil indicators (Y) represents the upper and lower critical values, respectively. Soil values higher than the relative yield of 80% are considered adequate, 41%-80% moderate, and <40% considered low (Lopes et al., 2013).

2.6. Statistical Analysis and Map Generation

2.6.1. Stepwise regression model: To retain soil variables that contribute to yield, a fitted regression models were constructed to study the effect of the various soil properties on the relative yield of the two selected *Musa* cultivars (Ghosh and Devi, 2019). The general linear regression model used in the analysis can be expressed as (Eq.3):

$Y=\beta_0+\beta 1X1+\beta 2X2+\beta 3X3+...+\beta nXn+\varepsilon$…..(3)

where Y represents the relative yield (%), β_0 is the intercept, β1–βn are regression coefficients, X1–Xn represent the independent soil variables (pH, EC, SOC, N, P, K, soil moisture, BD, clay content, CEC, TN), and **ε** is the error term. A stepwise variable selection procedure was applied to determine the most significant predictors influencing yield, where variables were sequentially entered into or removed from the model based on their statistical significance ($p < 0.05$). Statistical analyses were implimented using SPSS version 26.0. Map generated using QGIS (4.0)

3. RESULTS AND DISCUSSION

3.1. Agronomic Performance of *Musa* Cultivars

3.1.1. Atsu Mungo: Vegetative and yield traits varied by site (Table 4). Plant height and sucker number were greater

Table 3. Agronomic traits

Agronomic trait	Parameters	Details
Vegetative	Plant girth (cm)	Measured at 1m, above ground during flowering
	Plant height (cm)	The distance from the ground to the angle made between the bunch stalk and bunch cover leaf
	Number of suckers	Number of suckers produced during flowering
	Number of functional leaves	Counted at flowering, leaves with at least 50% of the green area
Maturity	Plant cycle (days)	Number of days between harvest date and planting date
	Days to flowering	Number of days from planting to flowering
	Flowering to harvest (days)	Number of days from flowering to harvesting
Fruit yield	Bunch weight (kg)	Fruit weight at harvest
	Number of fruits	Number of fruits at harvest
	Number of hands	Number of hands during harvest
	Fruit filling index	Sum of bunch weight divided by the number of days from flowering to harvest

Table 4. Agronomic performance of *Musa* cultivar Atsu Mungo

Agronomic trait		JL	AJL3	AJLB	AJL12
Vegetative	Plant girth (cm)	42.66[a]	41.33[b]	47.3[ab]	52[b]
	Plant height (cm)	290.3[a]	345[c]	316[b]	329.66[bc]
	Number of suckers	2[a]	2.33[a]	3.66[ab]	4.6[b]
	Number of functional leaves	7.6[a]	11.66[b]	10.66[b]	13.33[b]
Maturity	Plant cycle (days)	672[c]	596[b]	461[a]	435[a]
	Days to flowering	520[b]	503.66[b]	358.66[a]	337.66[a]
	Flowering to harvest (days)	137[b]	92.33[a]	102.33[a]	97.33[a]
Fruit yield	Bunch weight (kg)	9.68[a]	11.73[b]	14.67[c]	17.33[d]
	Number of fruits	52.33[a]	54.00[a]	67.00[a]	55.67[a]
	Number of hands	5.33[a]	5.33[a]	5.33[a]	6.00[a]
	Fruit filling index	0.0622[a]	0.1285[b]	0.1447[b]	0.178[c]
	Expected fruit yield (t ha^{-1} $year^{-1}$)	0.0057[a]	0.0078[b]	0.0127[c]	0.0160[d]
	Relative yield	55.87[a]	67.705[b]	84.63[c]	100[d]

Values in the same row with different superscripts are significantly by Duncan's multiple range test (p<0.05). JL: Jhum land; AJL3: Abandoned Jhum land 3; AJLB: Abandoned Jhum land with bamboo; AJL12: Abandoned Jhum land 12.

under longer fallow/bamboo sites, while JL consistently showed inferior values. Maturity traits (cycle length, days to flowering) were shortest at AJL12 and longest at JL ($p \leq 0.05$), indicating faster phenology with better soil conditions. Bunch weight and expected yield were highest at AJL12 and lowest at JL. Fruit number and hands were similar, highlighting that source–sink strength (fruit filling index) and biomass allocation, not merely fruit counts, drove yield differences. Relative yield followed the same gradient (AJL12 > AJLB > AJL3 > JL).

3.1.2. Aot Mungo: Most agronomic patterns paralleled Atsu Mungo (Table 5). Height peaked at AJL3, but overall yield attributes (bunch weight, fruit filling index, expected yield, relative yield) were highest at AJL12/AJLB and lowest at JL. Cycle length and days to flowering shortened with improved soils, again indicating that edaphic recovery accelerates phenology and yield formation. Across both cultivars, sites with greater clay and moisture i.e., AJLB and AJL12 (Tables 7 and 8) produced taller plants, more functional leaves and higher bunch weight, aligning with reports that texture-mediated water and nutrient retention supports root development, photosynthetic capacity and yield (Alhaj et al., 2019; Cardone et al., 2020). Conversely, the high BD/low SOC state at JL constrained growth—typical of rapidly growing herbaceous crops under suboptimal environments (Grime 2006).

3.2. Critical Limits and Site Categorization

Critical-limit analysis (Table 6) placed AJLB and AJL12 in the adequate category for most parameters in both cultivars, consistent with their superior performance. JL frequently fell in moderate (and low EC for Aot), while AJL3 remained mostly moderate except pH (Adequate). These categories mirror the yield gradient and reflect the role of litter inputs, mineralization and SOC build-up under longer fallow and bamboo. Short fallows (<5 years) depress soil nutrients and output–input energy ratios relative to older fallows (Datta and Singh 2012). The bamboo effect is also evident in the present study: ***AJLB > AJL3*** for SOC, N, P and moisture with lower BD matching observations of bamboo plantations enhancing microbial biomass and SOC turnover (Arunachalam and Arunachalam 2000; Mishra et al., 2014; Shilla and Mir 2017 Shia et al., 2017).

3.3. Soil–yield Relationships (Stepwise regression)

Stepwise regression analysis was implimented to evaluate the impact of soil properties on the relative yield of the Aot Mungo cultivar (Table 11). The fitted regression model was:.

YieldAot=7.845 +1.553 (CLAY)+ 0.687 (MOISTURE)

The model was statistically significant ($R^2 = 0.930$, $p = 0.017$). Clay ($\beta = 1.553$, $p = 0.005$) and soil moisture ($\beta = 0.687$, $p = 0.017$) showed positive relationships with relative yield.

For Atsu Mungo, the fitted regression model was: Yield Atsu=58.793+1.254 (clay) + 0.853 (moisture) - 10.137(pH)

The model was statistically significant ($R^2 = 0.966$, p <

Table 5. Agronomic performance of *Musa* cultivar Aot Mungo

Agronomic trait		JL	AJL3	AJLB	AJL12
Vegetative	Plant girth (cm)	61.33[a]	65.00[ab]	66.00[b]	67.00[b]
	Plant height (cm)	404.00[b]	427.00[b]	320.33[a]	311.33[a]
	Number of suckers	2.67[a]	2.33[a]	3.67[ab]	4.33[b]
	Number of functional leaves	9.67[a]	13.33[b]	12.67[b]	14.33[b]
Maturity	Plant cycle (days)	639.67[b]	612.67[b]	491.33[a]	440.67[a]
	Planting to flowering	491.00[d]	482.00[bc]	395.67[ab]	357.00[a]
	Flowering to harvest(days)	159.75[a]	130.67[a]	95.67[a]	83.67[a]
Fruit yield	Bunch weight (kg)	14.50[a]	16.00[b]	20.37[c]	22.57[d]
	Number of fruits	93.33[a]	151.00[a]	103.33[a]	221.33[b]
	Number of hands	9.33[b]	10.67[bc]	8.67[a]	12.33[c]
	Fruit filling index	0.090[a]	0.126[a]	0.243[b]	0.235[b]
	Expected fruit yield (t ha^{-1} $year^{-1}$)	0.0090[a]	0.01045[a]	0.0185[b]	0.0185[b]
	Relative yield	64.25[a]	70.90[b]	90.25[c]	99.99[d]

Values in the same row with different superscripts are significantly by Duncan's multiple range test (p<0.05). JL: Jhum land; AJL3: Abandoned Jhum land 3; AJLB: Abandoned Jhum land with bamboo; AJL12: Abandoned Jhum land 12.

Table 6. Critical limits of soil quality indicators

Soil properties	Relative yield (%)	Musa cultivars			
		Aot Mungo		Atsu Mungo	
pH	40	5.90	$r^2 = 0.860$	5.78	$r^2 = 0.928$
	80	5.26		5.20	
EC (dS m^{-1})	40	0.17	$r^2 = 0.895$	0.05	$r^2 = 0.940$
	80	0.42		0.48	
SOC (%)	40	0.42	$r^2 = 0.919$	0.80	$r^2 = 0.976$
	80	2.43		2.62	
N_{av}(Kg ha^{-1})	40	137.39	$r^2 = 0.946$	196.09	$r^2 = 0.900$
	80	385.36		407.11	
K_{av} (Kg ha^{-1})	40	34.84	$r^2 = 0.987$	62.43	$r^2 = 0.939$
	80	151.43		161.65	
P_{av} (Kg ha^{-1})	40	11.15	$r^2 = 0.945$	14.62	$r^2 = 0.951$
	80	27.35		28.80	
Moisture (%)	40	16.80	$r^2 = 0.986$	21.99	$r^2 = 0.995$
	80	41.13		43.31	
BD (g cm^{-3})	40	2.54	$r^2 = 0.884$	2.31	$r^2 = 0.890$
	80	1.47		1.37	
Clay (%)	40	14.76	$r^2 = 0.933$	17.46	$r^2 = 0.972$
	80	28.22		29.44	
CEC (meq100g^{-1})	40	3.77	$r^2 = 0.956$	8.18	$r^2 = 0.925$
	80	22.97		24.66	
TN (%)	40	0.42	$r^2 = 0.956$	0.62	$r^2 = 0.946$
	80	1.32		1.40	
Sand (%)	40	61.00	$r^2 = 0.987$	57.01	$r^2 = 0.949$
	80	43.86		42.35	
Silt (%)	40	19.40	$r^2 = 0.912$	20.95	$r^2 = 0.927$
	80	26.77		27.43	

Table 7. Classification of soil based on the critical limits of soil quality indicators for Aot Mungo

Site	pH	EC (dS m^{-1})	SOC (%)	N (Kg ha^{-1})	K (Kg ha^{-1})	P (Kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq100g^{-1})	TN (%)	Sand (%)	Silt (%)
JL	*5.63^{c}	**0.11^{a}	*1.40^{a}	*274.29^{a}	*106.01^{a}	*19.11^{a}	*31.15^{a}	*2.07^{c}	*21.20^{a}	*14.06^{a}	*0.88^{a}	*50.95^{d}	*22.79^{a}
AJL3	5.12^{b}	*0.39^{b}	*2.25^{b}	*326.50^{a}	*118.34^{ab}	*25.11^{ab}	*35.86^{a}	*1.58^{b}	*26.90^{b}	*18.96^{b}	*1.16^{b}	*48.25^{c}	*26.00^{b}
AJLB	5.13^{b}	0.57^{c}	2.76^{c}	480.59^{b}	188.00^{bc}	32.30^{bc}	45.63^{b}	1.08^{a}	31.28^{c}	29.82^{c}	1.61^{c}	38.44^{b}	29.11^{b}
AJL12	4.93^{a}	0.70^{d}	3.51^{d}	484.88^{b}	205.0^{c}	34.49^{d}	54.30^{c}	1.04^{a}	34.84^{d}	30.95^{c}	1.71^{c}	36.09^{a}	29.91^{c}

*****=Low, *=Moderate, Na= Adequate***

Table 8. Classification of soil based on the critical limits of soil quality indicators for Atsu Mungo

Site	pH	EC (dS m^{-1})	SOC (%)	N (Kg ha^{-1})	K (Kg ha^{-1})	P (Kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq100g^{-1})	TN (%)	Sand (%)	Silt (%)
JL	*5.6^{c}	*0.11^{a}	*1.40^{a}	*274.29^{a}	*106.01^{a}	*19.11^{a}	*31.15^{a}	*2.07^{c}	*21.20^{a}	*14.06^{a}	*0.885^{a}	*50.95^{d}	*22.79^{a}
AJL3	5.12^{b}	*0.39^{b}	*2.25^{b}	*326.50^{a}	*118.34^{ab}	*25.11^{ab}	*35.86^{a}	*1.58^{b}	26.90^{b}	*18.96^{b}	*1.166^{b}	*48.25^{c}	*26.00^{b}
AJLB	5.13^{b}	0.57^{c}	2.76^{c}	480.59^{b}	188.00^{bc}	32.30^{bc}	45.63^{b}	1.08^{a}	31.28^{c}	29.82^{c}	1.616^{c}	38.44^{b}	29.11^{b}
AJL12	4.93^{a}	0.70^{d}	3.51^{d}	484.88^{b}	205.0^{c}	34.49^{d}	54.30^{c}	1.04^{a}	34.84^{d}	30.95^{c}	1.710^{c}	36.09^{a}	29.91^{c}

*****=Low, *=Moderate, Na= Adequate***

0.001). Clay (β = 1.254, p = 0.025) and soil moisture (β = 0.853, p = 0.004) positively influenced relative yield, whereas pH showed a negative association (β = −10.137, p = 0.040). All predictors retained in the final model were statistically significant ($p < 0.05$) (Table 9).

Moisture governs canopy development and leaf area, so deficits suppress productivity (Carr 2009; Stevens et al., 2020). This in response may led to increased disease risks and reduce yield (Olivares et al., 2021). Clay content in soil supports structural stability, nutrient retention and buffering (Newman 1984). Hence, these soil factors are crucial for adequate banana growth. In contrast, elevated pH under recent burning can impair nutrient availability (Shahid et al., 2013), explaining the negative pH coefficient. Overall, regression results reinforce the bamboo- and fallow-mediated improvements in clay-related structure and moisture storage that underpin higher yields at AJLB and AJL12.

4. CONCLUSION

This study addresses the impact of fallow practices on the agronomic performance of *Musa* cultivars within the context of land degradation, mitigation, and rehabilitation in terrestrial environments. Establishing soil quality indicators is vital for achieving efficient productivity and sustainable management goals. All soil parameters for both cultivars fell within the "Adequate category" at sites AJLB and AJL12.

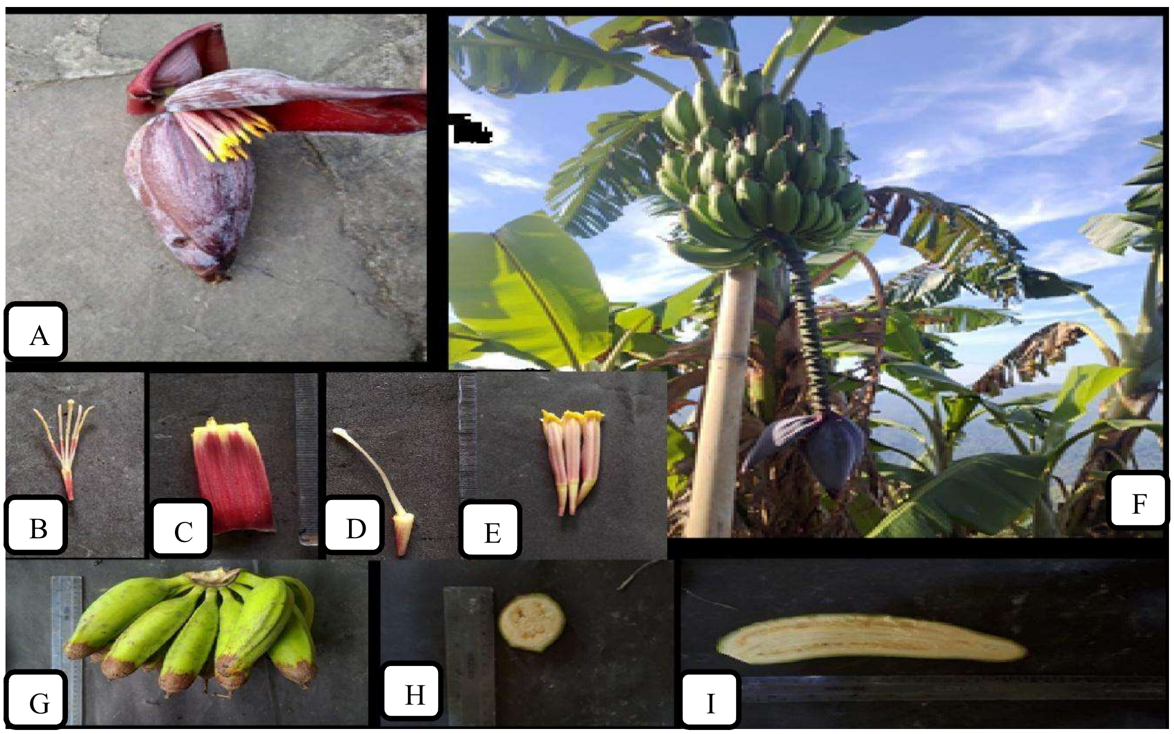

Figure 3. *Musa* cultivar: Atsu Mungo (Ao Naga) with various floral parts in picture. A: Banana inflorescence. B: Stamens. C: Tepal. D: Style and stigma. E: Male Flowers. F: Banana flowering. G: Banana bunch. H: Transverse section of fruit. I: Longitudinal section of fruit

Table 9. Model summary of stepwise regression of soil properties and relative yield

		R	R^2	Adjusted R^2	Std. Error	R^2 Change	F Change	*p* value
Aot Mungo	Model 1: Clay	.943[a]	.890	.882	5.13175	.890	112.882	<.001
	Model 2: Clay, Moisture	.964[b]	.930	.919	4.24333	.040	7.476	.017
Atsu Mungo	Model 1: Clay	.959[a]	.919	.913	5.13222	.919	158.435	<.001
	Model 2: Clay, Moisture	.975[b]	.951	.944	4.13532	.032	8.564	.012
	Model 3: Clay, Moisture, pH	.983[c]	.966	.958	3.58596	.015	5.288	.040

Dependent variable: Relative yield; predictors retained at p < 0.05

However, there were variations at other sites, with some parameters falling into the moderate" category. These variations indicate decreased plant performance at certain sites, which can be attributed to reduced soil nutrient levels associated with land degradation. The findings suggest that while a long fallow period (<12 years) facilitates maximum soil regeneration, incorporating *B. tulda* into degraded Jhum soil leads to significant improvements in soil organic carbon, macronutrient levels, clay content, and moisture. This highlights the potential of *B. tulda* plantation to expedite soil recovery in degraded Jhum lands, promoting sustainable land management practices.

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CRediT Authorship Contribution Statement

Wati Temjen: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing, original draft Writing, review & editing. Maibam Romeo Singh: Investigation, Methodology, Supervision, Writing, review & editing. Tali Ajungla: Conceptualization, Supervision, Writing, review & editing. Merenlemla Jamir: Resources, Software, Validation, Writing, review & editing. Watitoshi Ao: Methodology, Software, Validation, Writing, review & editing. Nuksungmenla Jamir**:** Formal analysis, Investigation, Resources, Validation, Writing, review & editing.

Conflict of Interest

All Authors declare no conflict of interest.

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Available on request from the corresponding author.

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