



Parametric Suitability Assessment of the Limawa Integrated Farm and Orchard for Sustainable Mango (*Mangifera indica* L.) Production in Minna, Nigeria

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Abstract

A detailed soil survey was conducted at the Limawa Integrated Farm and Orchard, Minna, Nigeria, to evaluate Southern Guinea Savanna soils for sustainable mango (*Mangifera indica* L.) production. Using a rigid grid survey, four soil mapping units (LMU1 to LMU4) were delineated, and surface samples (0–30 cm) were analyzed for physicochemical properties. Results showed predominantly coarse-textured soils, with sand ranging from 867 to 917 g kg⁻¹, silt from 28 to 83 g kg⁻¹, and clay from 50 to 65 g kg⁻¹. LMU1, LMU2, and LMU4 were imperfectly drained, whereas LMU3 was poorly drained. Soil reaction was neutral to slightly alkaline (pH H₂O 6.9–7.7). Soil fertility was inherently low, characterized by low organic carbon (1.68–2.88 g kg⁻¹), available phosphorus (5–9 mg kg⁻¹), and CEC (4.0–7.0 cmol(+)/kg). Parametric Storie Index evaluation indicated that under current management, LMU1 and LMU3 are Permanently Not Suitable (N2), while LMU2 and LMU4 are Currently Not Suitable (N1). However, with targeted inputs, including drainage control, organic amendments, balanced fertilization, and supplemental irrigation, potential suitability improves to Marginally Suitable (S3) for LMU1 and LMU3, and Moderately Suitable (S2) for LMU2 and LMU4.

Keywords: Land Evaluation, Parametric Indexing, Storie Index, Soil Characterization, Guinea Savanna.

1.0 INTRODUCTION

Soil is the primary foundation for agricultural production, fiber provision, and industrial raw material supply. A thorough understanding of soil properties is imperative for driving sustainable land use and optimizing natural resource management (Soil Science Division Staff, 2017). Land-use planning and agricultural decision-making rely fundamentally on site-specific soil characteristics. In this context, soil surveys serve as indispensable tools by mapping, characterizing, and evaluating soil entities while highlighting their susceptibility to erosion and functional land-use limitations. The resulting data enable land planners to formulate sustainable land-use strategies and predict the environmental impacts of proposed agricultural interventions (Joshua *et al.*, 2022).

Land evaluation systematically measures and interprets land qualities to determine their suitability for alternative land utilization types (LUTs). This process relies on comparing crop-specific requirements with prevailing land characteristics (Abdelrahman *et al.*, 2022). Land suitability classification, such as the widely adopted FAO Framework for Land Evaluation, defines the fitness of a given land unit for specific agricultural or non-agricultural purposes under defined management systems (Food and Agriculture Organization of the United Nations [FAO], 2007).

Detailed soil characterization and land evaluation remain pivotal strategies for achieving environmental sustainability (Chukwu *et al.*, 2014). Effective evaluation requires integrating climate, soil, vegetation, and topographic datasets to predict land performance under specified uses. However, land suitability assessments are infrequently applied in developing tropical agricultural systems, leading to sub-optimal management and land misuse. Intensive agricultural expansion without prior site assessment has exacerbated soil degradation, depleted soil quality indicators (such as organic carbon, pH, and macro-nutrients), and disrupted ecological balances (Ambali *et al.*, 2024).

Establishing commercial perennial fruit orchards, such as mango (*Mangifera indica* L.), requires long-term capital investment and site-specific land suitability assessment. Recent studies on Nigerian mango production highlight increased vulnerability to climate variability and soil nutrient depletion (Lawal *et al.*, 2023), underscoring the urgent need for local pedological evaluations. Despite the expansive agricultural land in Minna, Niger State, quantitative site suitability assessments for tree crop orchards is limited. The primary objective of this study was to evaluate the suitability of the soils at Limawa Integrated Farm and Orchard, Minna, for sustainable mango production using a parametric indexing approach.

2.0 MATERIALS AND METHODS

2.1 Study Area

The experiment was conducted at the Limawa Integrated Farm and Orchard, located along the Minna–Bida road, Minna, Niger State, Nigeria (Latitude 09° 33' 22.8" N, Longitude 06° 28' 46.6" E). The area falls within the Southern Guinea Savanna agro-ecological zone of Nigeria. The climate is sub-humid, with a mean annual rainfall of approximately 1284 mm, distributed over a single wet season (April–October) and a distinct 5-month dry season (November–March). Mean annual maximum temperatures average 33.5 °C, peaking between February and April (Weather Spark, 2022). Geology comprises basement complex rocks (granites, gneisses, and migmatites) forming undulating high plains dominated by saprolitic parent materials (Ojanuga, 2006).

2.2 Field Survey and Soil Sampling

A detailed soil survey was conducted using a rigid grid technique. A baseline was established across the study area, with parallel transects laid out at 50 m intervals. Soil auger observations were made every 50 m along each transect to a depth of 100 cm (or to a root-restricting layer) for morphological characterization. Four distinct land mapping units were delineated: LMU1, LMU2, LMU3, and LMU4. Duplicate representative soil samples were collected from the surface layer (0–30 cm) of each unit, air-dried at room temperature (25 °C), crushed in a porcelain mortar, and passed through 2 mm and 0.5 mm stainless steel sieves before laboratory analyses.

2.3 Laboratory Analyses

Laboratory procedures followed standard protocols outlined by (IITA, 2015):

- **Particle Size Distribution:** Determined via the Bouyoucos hydrometer method using sodium hexametaphosphate ($\text{NaPO}_3)_6$ as a dispersing agent.
- **Soil Reaction (pH):** Measured potentiometrically in both 1:2.5 soil-to-water (pH H_2O) and 1:2.5 soil-to-0.01 M CaCl_2 (pH CaCl_2) suspensions.
- **Organic Carbon (OC):** Analyzed via the Walkley–Black chromic acid wet oxidation method.
- **Available Phosphorus (Av. P):** Extracted using Bray No. 1 solution and determined colorimetrically.
- **Exchangeable Bases (Ca^{2+} , Mg^{2+} , K^+ , Na^+):** Extracted with neutral 1 M NH_4OAc (pH 7.0). Ca^{2+} and Mg^{2+} were measured using Atomic Absorption Spectrophotometry (AAS), while K^+ and Na^+ were determined by flame photometry.
- **Exchangeable Acidity ($\text{Al}^{3+} + \text{H}^+$):** Extracted with unbuffered 1 M KCl and titrated against 0.05 M NaOH .
- **Cation Exchange Capacity (CEC):** Determined by the 1 M NH_4OAc (pH 7.0) saturation method. Effective Cation Exchange Capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity.

2.4 Land Suitability Assessment Framework

Land evaluation was performed using the Storrie Index parametric method (El Baroudy *et al.*, 2020). The Suitability Index (SI) was computed using the multiplicative equation:

$$SI = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \dots$$

Where:

- SI = Suitability Index
- A = Rating value of the most limiting land characteristic
- $B, C, D, \dots$ = Rating values for remaining land characteristics

Computed index values were matched against standard FAO qualitative suitability classes (Table 1). Soil chemical parameters were evaluated against critical nutrient thresholds for tropical savanna soils (Table 2).

Table 1: Land Suitability Classes and Corresponding Suitability Index (SI) Ranges

Class	Intensity of limitation	Land indices
S1	Highly suitable	75 – 100
S2	Moderately suitable	50 – 75
S3	Marginally suitable	25 – 50
N1	Currently not suitable	12.5 – 25
N2	Permanently not suitable	0 – 12.5

Source: Source: Sys et al., (1991); Lawal et al. (2023).

Table 2: Critical Limits for Interpreting Soil Nutrient Levels in Savanna Soils

Parameter	Unit	Low	Medium	High
Exchangeable Ca ²⁺	cmol(+)/kg	< 2.0	2.0 – 5.0	> 5.0
Exchangeable Mg ²⁺	cmol(+)/kg	< 0.3	0.3 – 1.0	> 1.0
Exchangeable K ⁺	cmol(+)/kg	< 0.15	0.15 – 0.30	> 0.30
Exchangeable Na ⁺	cmol(+)/kg	< 0.10	0.10 – 0.30	> 0.30
Cation Exchange Capacity (CEC)	cmol(+)/kg	< 6.0	6.0 – 12.0	> 12.0
Organic Carbon	g kg ⁻¹	< 10.0	10.0 – 15.0	> 15.0
Total Nitrogen	g kg ⁻¹	< 1.0	1.0 – 2.0	> 2.0
Available Phosphorus	mg kg ⁻¹	< 10.0	10.0 – 20.0	> 20.0
Base Saturation	%	< 50.0	50.0 – 80.0	> 80.0

Source: Shehu et al. (2015).

3.0 RESULTS

3.1 Morphological Characteristics

The morphological properties of the four soil units are presented in Table 3 and the soil map obtained is shown in Figure 1. Surface soils in LMU1 exhibited a brown (10YR 4/3) hue without mottles over a yellowish-brown (10YR 5/4) subsurface horizon with strong brown (10YR 5/6) mottles. LMU2 exhibited pale brown (10YR 6/3) surface colors underlain by greyish brown (10YR 5/2) subsoil horizons containing prominent manganese concretions. LMU3 displayed yellow brown (10YR 5/6) surface matrices over pale brown (10YR 6/3) horizons with red (2.5YR 2/6) mottling. LMU4 surface horizons were dark greyish brown (10YR 4/2) with common brown (7.5YR 4/4) mottles.

Solum depth varied across mapping units: LMU1 and LMU3 were moderately deep (60 cm), limited by underlying plinthite/saprolite layers, whereas LMU2 and LMU4 were deep (> 100 cm). Hydromorphic drainage conditions were predominant; LMU1, LMU2, and LMU4 were imperfectly drained, whereas LMU3 (situated in a valley depression) was poorly drained.

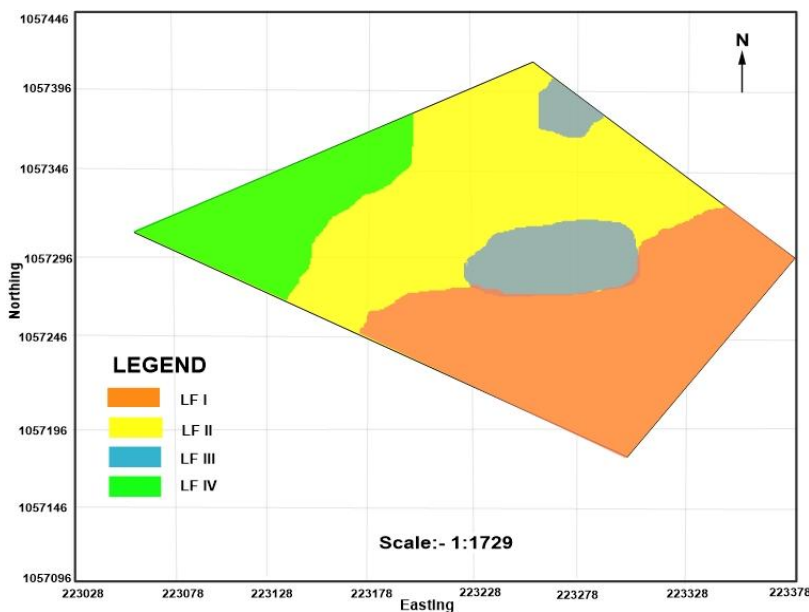


Figure 1: Soil map of Limawa Integrated Farms and Orchard, Minna

Table 3: Morphological Properties of the Soil Mapping Units at Limawa Integrated Farm

Unit	Depth (cm)	Matrix Color	Mottles	Slope Position	Drainage	Consistence (Wet / Moist)
LMU1	0–30	10YR 4/3 Brown	None	Moderate Slope	Imperfect	Slightly sticky, very plastic / Slightly friable
	30–60	10YR 5/4 Yellowish brown	Present	Moderate Slope	Imperfect	Slightly sticky, plastic / Friable
LMU2	0–10	10YR 6/3 Pale brown	Faint (7.5YR 5/6)	Lower Slope	Imperfect	Non-sticky, non-plastic / Moderately loose
	10–60	10YR 5/2 Grayish brown	Prominent (7.5YR 5/6)	Lower Slope	Imperfect	Slightly sticky, plastic / Very firm
	60–100	10YR 5/2 Grayish brown	Prominent (7.5YR 5/6)	Lower Slope	Imperfect	Slightly sticky, plastic / Very firm
LMU3	0–30	10YR 5/6 Yellow brown	Strong brown (7.5YR 5/6)	Valley Bottom	Poor	Non-sticky, non-plastic / Very friable
	30–60	10YR 6/3 Pale brown	Red (2.5YR 2/6)	Valley Bottom	Poor	Slightly sticky, plastic / Friable
LMU4	0–30	10YR 4/2 Dark grayish brown	Brown (7.5YR 4/4)	Lower Slope	Imperfect	Non-sticky, slightly plastic / Very friable
	30–60	10YR 4/2 Dark grayish brown	Brown (7.5YR 4/4)	Lower Slope	Imperfect	Non-sticky, non-plastic / Very friable

3.2 Physical Properties

The physical properties of the topsoil (0–30 cm) are presented in Table 4. All soil units were heavily dominated by the sand fraction, ranging from 867 to 917 g kg⁻¹. Silt content was consistently low, ranging between 28 and 83 g kg⁻¹, and clay content was similarly minimal, ranging from 50 to 65 g kg⁻¹. Consequently, textural classes ranged from Sand to Sandy Loam and Loamy Sand. The silt/clay ratio varied between 0.51 and 1.66 across sampling points.

Table 4: Particle Size Distribution and Textural Classes of Surface Soils (0–30 cm)

Mapping Unit	Sampling Point	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Textural Class	Silt:Clay Ratio
LMU1	P1	892	43	65	Loamy sand	0.66
	P16	902	33	65	Sand	0.51
LMU2	P10	867	83	50	Sandy loam	1.66
	P12	897	48	55	Loamy sand	0.87
LMU3	P3	917	28	55	Sand	0.51
	P13	902	33	65	Loamy sand	0.51
LMU4	P6	882	53	65	Sandy loam	0.81
	P8	897	53	50	Sandy loam	1.06

3.3 Chemical Properties

Soil chemical properties are summarized in Table 5. Soil reaction (pH H₂O) was neutral to slightly alkaline, ranging from 6.9 to 7.7, while pH CaCl₂ ranged from 5.5 to 6.4. Soil organic carbon was uniformly low across all units (1.68–2.88 g kg⁻¹). Available phosphorus levels were severely depleted (5.0–9.0 mg kg⁻¹).

Exchangeable calcium dominated the exchange complex (4.4–7.0 cmol(+)/kg). Exchangeable magnesium was low (0.6–1.6 cmol(+)/kg), exchangeable sodium was low to moderate (0.17–0.24 cmol(+)/kg), and exchangeable potassium was deficient (0.05–0.16 cmol(+)/kg). Cation exchange capacity (CEC) ranged from 4.0 to 7.0 cmol(+)/kg, reflecting a low nutrient retention potential. Base saturation was high across all mapping units (91–96%).

Table 5: Chemical Properties of Surface Soil Horizons (0–30 cm)s

Unit	Pt	pH H ₂ O	pH CaCl ₂	OC (g kg ⁻¹)	Av.P (mg kg ⁻¹)	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Exch. Acid.	CEC	ECEC	BS (%)
						← cmol(+)/kg →							
LMU1	1	7.7	6.4	2.40	7.0	6.6	1.0	0.22	0.16	0.48	5.0	8.46	94
	16	7.0	5.9	2.88	9.0	6.8	0.8	0.20	0.13	0.55	7.0	8.48	93
LMU2	10	7.1	5.8	1.92	7.0	4.4	1.6	0.19	0.07	0.60	7.0	6.86	91
	12	6.9	5.8	1.68	7.0	6.6	0.6	0.18	0.05	0.53	6.0	7.96	92
LMU3	3	7.2	6.1	1.80	7.0	6.6	1.6	0.24	0.12	0.43	4.0	8.99	95
	13	7.0	6.4	1.80	5.0	6.2	1.6	0.21	0.12	0.40	6.0	8.53	95
LMU4	6	7.6	5.5	1.68	9.0	7.0	1.0	0.18	0.09	0.45	5.0	8.72	95
	8	7.2	5.8	2.04	6.0	6.8	1.6	0.17	0.07	0.38	4.0	9.02	96

Note: Pt = Points; OC = Organic Carbon; Av.P = Available Phosphorus; Exch. Acid. = Exchangeable Acidity (Al³⁺ + H⁺); CEC = Cation Exchange Capacity; ECEC = Effective Cation Exchange Capacity; BS = Base Saturation

3.4 Land Suitability Assessment

3.4.1 Current Land Suitability

The current suitability ratings for mango production are presented in Table 6. Under unimproved natural conditions, LMU1 and LMU3 scored Suitability Indices (SI) of 1.97 and 1.32, respectively, placing them in Class N2 (Permanently Not Suitable). LMU2 and LMU4 both achieved an SI of 17.79, categorizing them as Class N1 (Currently Not Suitable). Coarse soil texture, inadequate effective rooting depth, poor internal drainage, and severe phosphorus deficiencies were the primary drivers limiting overall performance.

Table 6: Parametric Evaluation of Current Land Suitability (SI) for Mango

Land Requirement / Parameter	LMU1 Rating Score	LMU2 Rating Score	LMU3 Rating Score	LMU4 Rating Score
Mean Rainfall (mm)	S2 (75)	S2 (75)	S2 (75)	S2 (75)
Mean Temperature (°C)	S2 (75)	S2 (75)	S2 (75)	S2 (75)
Drainage Class	S2 (75)	S2 (75)	S2 (75)	S2 (75)
Surface Texture	N2 (12.5)	S2 (75)	N2 (12.5)	S2 (75)
Soil Depth (cm)	S3 (50)	S2 (75)	S3 (50)	S2 (75)
CEC (cmol+)/kg	S2 (75)	S2 (75)	S2 (75)	S2 (75)
Base Saturation (%)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
pH H ₂ O	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Organic Carbon (g kg ⁻¹)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Sodicity (ESP, %)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Slope Score	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Calculated Suitability Index (SI)	1.97	17.79	1.32	17.79
Current Suitability Class	N2	N1	N2	N1

Calculation Example (LMU1):

$$SI = 12.5 \times 0.75 \times 0.75 \times 0.75 \times 1.00 \times 0.50 \times 0.75 \times 1.00 \times 1.00 \times 1.00 \times 1.00 = 1.97$$

3.4.2 Potential Land Suitability

With the assumption that feasible agricultural interventions (drainage installation, deep tillage, organic manuring, and balanced fertigation) are applied, potential land suitability scores improved markedly (Table 7). LMU1 and LMU3 upgraded to Class S3 (Marginally Suitable; SI = 4.68), while LMU2 and LMU4 improved to Class S2 (Moderately Suitable; SI = 42.20).

Table 7: Parametric Evaluation of Potential Land Suitability (SI) for Mango

Land Requirement / Parameter	LMU1 Rating Score	LMU2 Rating Score	LMU3 Rating Score	LMU4 Rating Score
Mean Rainfall (mm)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Mean Temperature (°C)	S2 (75)	S2 (75)	S2 (75)	S2 (75)
Drainage Class	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Surface Texture	N1 (12.5)	S2 (75)	N1 (12.5)	S2 (75)
Soil Depth (cm)	S3 (50)	S2 (75)	S3 (50)	S2 (75)
CEC (cmol(+)/kg)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Base Saturation (%)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
pH H ₂ O	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Organic Carbon (g kg ⁻¹)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Sodicity (ESP, %)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Slope Score	S1 (100)	S1 (100)	S1 (100)	S1 (100)
Calculated Suitability Index (SI)	4.68	42.20	4.68	42.20
Potential Suitability Class	S3	S2	S3	S2

4.0 DISCUSSION

4.1 Morphological and Physical Properties

The soil matrix colors (10YR hues) accompanied by redoximorphic mottling in LMU1, LMU2, and LMU4 indicate periodic waterlogging and fluctuating water table conditions. In LMU3, intense mottling and lower matrix chromas stem from its low topography in a valley basin, promoting poor internal drainage and accumulation of goethite [FeO(OH)] minerals (Gómez Samus *et al.*, 2021). Mango trees are highly sensitive to prolonged root zone hypoxia, which restricts taproot growth and increases susceptibility to fungal root rot pathogens (Lawal *et al.*, 2023).

The high sand fraction (867–917 g kg⁻¹) across all soil units reflects the coarse nature of basement complex granitic saprolites in this region (Ojanuga, 2006). Surface clay loss is further exacerbated by water erosion, selective surface washing, and argillic clay migration down the profile (Sadiq *et al.*, 2025). Silt/clay ratios exceeding 0.25 across all LMUs suggest pedogenetically young soils with residual weatherable mineral reserves (Lawal *et al.*, 2014; Ukabiala *et al.*, 2021). However, the sand-dominated texture causes low moisture-holding capacities, high percolation losses, and poor structural stability.

4.2 Chemical Properties and Nutrient Dynamics

Soil pH values (6.9–7.7) are generally favorable for plant nutrient availability. However, organic carbon content (< 3.0 g kg⁻¹) is low, driven by high ambient temperatures, rapid oxidation, annual bush burning, and residue removal (Peter-Jerome *et al.*, 2022). Low organic matter directly accounts for the low CEC (4.0–7.0 cmol(+)/kg), indicating low nutrient retention capacity and dominance of kaolinitic clays and sesquioxides (Malgwi *et al.*, 2000; Sadiq *et al.*, 2025).

The low available phosphorus (< 10 mg kg⁻¹) and exchangeable potassium (< 0.20 cmol(+)/kg) represent critical chemical bottlenecks. Savanna soils in Central Nigeria are naturally P-limited due to low inherent phosphorus in the parent material and strong P-fixation capacity (Bebeley *et al.*, 2024; Oyun *et al.*, 2025). Potassium levels were below the minimum threshold of 0.15 cmol(+) kg⁻¹ required for optimal fruit yield and tree growth, except in LMU1, where potassium was at a medium level (Shehu *et al.*, 2015).

4.3 Land Suitability Synthesis

Under present management, the land is constrained by textural limitations, limited solum depth, imperfect drainage, and acute macronutrient deficiencies (Class N1 and N2). These findings align with Maroeto *et al.* (2024), who reported that physical soil depth, low CEC, and poor drainage are the primary constraints limiting fruit orchard performance in sub-humid savannas.

4.4 Recommendations

To upgrade potential land suitability to S2 (Moderately Suitable) and S3 (Marginally Suitable), the following soil management strategies are recommended:

1. Integrated Nutrient Management: Application of compost or farmyard manure (> 10 t ha⁻¹) combined with split applications of N-P-K mineral fertilizers to build soil organic matter, enhance CEC, and mitigate leaching losses.

2. Water and Drainage Management: Construction of ridges, mounds, or field drainage ditches around LMU3 and LMU1 to relieve high water tables during the rainy season. Supplemental drip irrigation should be deployed during the 5-month dry season to maintain root growth.
3. Physical Soil Conservation: Mulching of tree basins with crop residues to conserve soil moisture, suppress weed competition, lower soil temperatures, and protect sandy topsoil from erosion.

5.0 CONCLUSION

This study evaluated the land suitability of Limawa Integrated Farm and Orchard, Minna, for commercial mango production using parametric indexing. Currently, the soils are limited by coarse texture, shallow depth, poor drainage, and low intrinsic fertility (Classes N1 and N2). However, implementing targeted drainage, organic amendments, mulching, and balanced fertigation can upgrade potential land suitability to Classes S2 (Moderately Suitable) and S3 (Marginally Suitable).

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