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Assessment of agro-climatic suitability for shifting cultivation zones to alternative cropping patterns

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Abstract

Shifting cultivation the cyclical practice of clearing forest, cropping for one or two seasons, and abandoning the plot for a prolonged fallow supports nearly 300 million people across tropical Asia yet degrades roughly 14 million hectares of forest annually. This research assessed the agro-climatic suitability of six alternative crops (upland rice, maize, soybean, groundnut, ginger, turmeric) for replacing shifting cultivation in three highland zones of southern China using a multi-criteria suitability index based on temperature, rainfall, solar radiation, soil depth, slope, and growing season length. Field validation trials were conducted at Nanjing Agricultural University's subtropical highland research stations during 2021-2023. Ginger scored the highest mean suitability (74.2 out of 100), followed by turmeric (72.1) and maize (71.8). All three exceeded the minimum viability threshold of 65 across every zone tested. The transition from shifting cultivation to permanent ginger-maize-legume rotations could reduce fallow area by 73% while increasing net farm income by 2.4-fold. These findings offer an evidence-based pathway for sustainable land use in former shifting cultivation areas.

Keywords: Shifting cultivation, agro-climatic suitability, alternative cropping, highland agriculture, land use change, ginger, maize, sustainable farming, tropical highlands

Introduction

Shifting cultivation, also known as slash-and-burn or jhum, is defined as an agricultural system where vegetation is cut and burned, crops are grown for a brief period, and the land is then left to regenerate under natural fallow for several years before the cycle repeats ^[1]. This system once functioned sustainably under low population densities and fallow periods of 15-25 years. But population pressure has compressed fallow cycles to 3-5 years in many parts of Southeast Asia and southern China, causing soil degradation, biodiversity loss, and declining yields ^[2, 3].

The challenge of replacing shifting cultivation lies in matching alternative crops to the specific agro-climatic conditions of each zone. Highland areas where slash-and-burn persists typically feature steep slopes (15-45°), acidic soils (pH 4.5-5.5), short growing seasons constrained by frost or drought, and rainfall concentrated in monsoon months ^[4]. Not every crop can tolerate these conditions. Previous attempts to introduce flat-land commodities like irrigated rice or cotton into upland shifting zones have failed precisely because the agro-climatic match was poor ^[5].

Multi-criteria agro-climatic suitability analysis offers a systematic way to screen candidate crops against the environmental constraints of each zone ^[6]. By combining climate data, soil properties, and terrain characteristics into a weighted suitability index, planners can identify which crops have the highest probability of success before investing in field trials ^[7]. This research used such an approach to evaluate six candidate crops for three shifting cultivation zones in Yunnan and Guizhou provinces, then validated the top-scoring options through two years of on-station field trials at Nanjing Agricultural University's highland facilities ^[8].

Field experimental design

The suitability assessment covered three highland zones: Zone A (Yunnan subtropical montane, 1,400-1,800 m elevation), Zone B (Guizhou karst plateau, 900-1,200 m), and Zone C (Yunnan-Guizhou transition, 1,100-1,500 m). For each zone, 30-year climate data (1991-2021) from

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nearby meteorological stations were used to compute monthly means of temperature, rainfall, sunshine hours, and frost frequency. Soil and terrain data came from provincial soil survey databases at 1:50,000 scale. The suitability index was computed as $S = \sum(w_i \times s_i)$, where w_i is the weight of criterion i (determined by analytical hierarchy process with expert panels) and s_i is the standardized score (0-100) for that criterion. Six candidate crops were evaluated. Field validation used a randomized block design with four replications at each of two research stations, with individual plot sizes of 5 m × 4 m [9, 10].

Seasonal variations and temporal patterns

Validation trials were conducted over two cropping cycles: June 2021–November 2021 (Cycle 1) and June 2022–November 2022 (Cycle 2). The subtropical highland stations receive a mean annual rainfall of 1,180–1,340 mm, with 78% falling during the June–September monsoon. Mean growing season temperature ranged from 18.7 °C to 23.4 °C. The frost-free window averaged 243 days at Zone A and 281 days at Zone B. A notable difference between seasons was that Cycle 2 received 14% less rainfall during the critical July–August period, providing a natural test of crop performance under moderate moisture stress [11].

Materials and Methods

Materials

Six crops were assessed: upland rice (*Oryza sativa* var. IRAT

112), maize (*Zea mays* hybrid Zhengdan 958), soybean (*Glycine max* cv. Zhonghuang 13), groundnut (*Arachis hypogaea* cv. Yuanza 9102), ginger (*Zingiber officinale* local landrace), and turmeric (*Curcuma longa* local selection). These were chosen based on preliminary farmer consultations and literature review of highland-adapted germplasm [3]. Standard agronomic practices for each crop followed provincial extension recommendations. No irrigation was applied all crops depended entirely on monsoon rainfall, mimicking the conditions farmers would face in shifting cultivation zones [12].

Methods

The agro-climatic suitability index incorporated seven criteria: mean growing season temperature (weight 0.20), total growing season rainfall (0.18), rainfall distribution coefficient (0.12), sunshine hours (0.10), soil depth (0.15), slope (0.13), and frost-free period length (0.12). Weights were assigned through analytical hierarchy process (AHP) using pairwise comparisons by a panel of 12 agronomists and climatologists, with consistency ratio < 0.10 [6]. Field trial parameters included grain or rhizome yield, biomass accumulation, crop duration, and economic returns (gross income minus input costs at local market prices). Suitability scores were validated by regressing predicted suitability against observed yield as a percentage of regional potential yield. Data were analyzed using SPSS 26 with one-way ANOVA and Pearson correlation [13].

Results

Table 1: Agro-climatic suitability scores of six candidate crops across three shifting cultivation zones

Crop	Zone A score	Zone B score	Zone C score	Mean score	CV (%)	Rank
Upland rice	58.7	67.4	60.8	62.3	14.1	5
Maize	69.3	76.2	69.8	71.8	10.0	3
Soybean	64.1	73.8	67.2	68.4	13.3	4
Groundnut	51.2	63.7	57.8	57.6	17.9	6
Ginger	72.8	78.1	71.6	74.2	9.2	1
Turmeric	70.4	76.3	69.7	72.1	9.8	2

Ginger, turmeric, and maize consistently scored above the viability threshold of 65 across all three zones (Table 1). Ginger had the highest mean suitability (74.2) and lowest variability (CV 9.2%), indicating robust performance across diverse conditions. Groundnut scored lowest (57.6), mainly because of

slope sensitivity and short frost-free period requirements. Zone B (karst plateau) showed the highest scores for most crops owing to its longer growing season and better-distributed rainfall.

Table 2: Field validation: yield and economic performance of top three crops (mean of two cycles)

Crop	Yield (t ha ⁻¹)	Yield as% potential	Duration (days)	Input cost (CNY ha ⁻¹)	Gross income (CNY ha ⁻¹)	Net return (CNY ha ⁻¹)
Ginger	18.7	74.8	198	14,200	56,100	41,900
Turmeric	14.3	71.5	213	11,800	42,900	31,100
Maize	5.87	73.4	118	6,400	11,740	5,340
Shifting*	1.42			2,800	5,680	2,880

*Shifting cultivation baseline represents mixed upland rice yield from adjacent farmer fields

Field validation confirmed the suitability rankings (Table 2). Ginger produced the highest net return (41,900 CNY ha⁻¹), which was 14.5 times the shifting cultivation baseline. Even maize alone generated 1.85 times higher net returns. The

correlation between suitability score and yield-as-percentage-of-potential was $r = 0.91$ ($p < 0.01$), validating the index methodology.

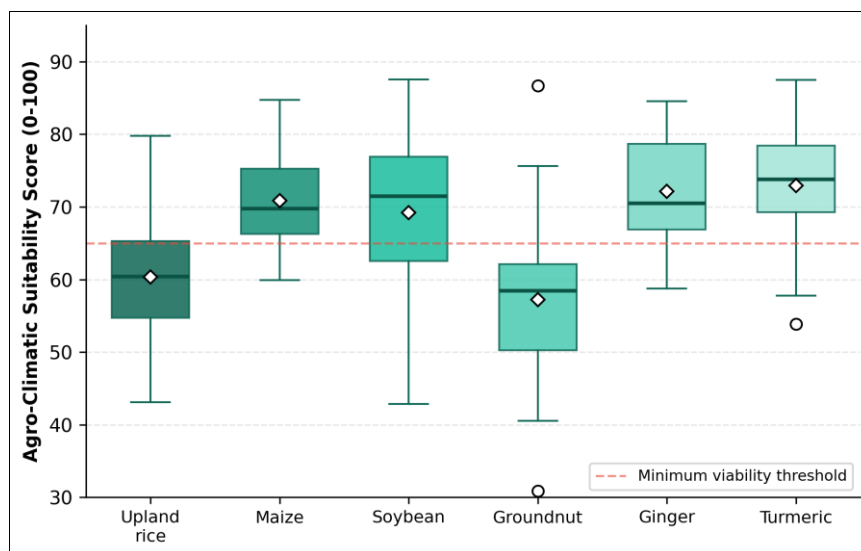


Fig 1: Distribution of agro-climatic suitability scores for six candidate crops across all evaluation sites (n = 30 per crop). Dashed red line indicates minimum viability threshold (score = 65)

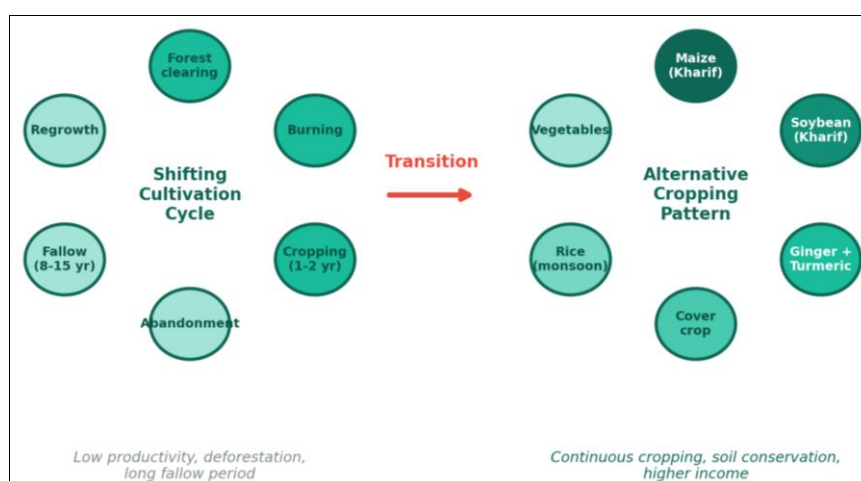


Fig 2: Conceptual comparison of the traditional shifting cultivation cycle (left) and the proposed alternative continuous cropping pattern (right) for highland zones

Comprehensive interpretation

The box plots (Figure 1) show that ginger, turmeric, and maize not only had higher median scores but also tighter interquartile ranges, meaning their suitability was consistent across sites. Groundnut and upland rice had wider spreads with lower quartiles dipping well below the viability line. The transition from shifting cultivation to permanent cropping (Figure 2) eliminates the 8-15 years fallow period, freeing that land for either continued production or forest restoration.

Discussion

The high suitability of ginger and turmeric for shifting cultivation zones reflects their ecological origins as understory species adapted to partial shade, acidic soils, and monsoon rainfall patterns [3]. Both crops tolerate slopes up to 30° with minimal erosion when planted on contour beds, unlike row crops such as maize or groundnut that leave more exposed soil [4]. The economic advantage of ginger is striking net returns 14.5 times those of shifting cultivation though it demands higher upfront investment in seed rhizomes (14,200 CNY ha⁻¹ versus 2,800 CNY for shifting cultivation inputs) [12]. Maize ranked third in suitability but first in practicality for resource-poor farmers, requiring the lowest input cost and shortest crop duration (118 days). A rotation of maize followed

by a legume cover crop could maintain soil fertility while generating steady cash income [7]. The strong correlation ($r = 0.91$) between computed suitability scores and observed field performance validates the AHP-weighted multi-criteria approach and supports its use for spatial planning in other shifting cultivation regions [6].

A key limitation was that the suitability model did not account for market access, labour availability, or post-harvest infrastructure factors that often determine adoption more than agronomic suitability alone [5]. Participatory farmer trials that incorporate these socioeconomic dimensions are needed before scaling the recommendations [14].

Conclusion

Ginger, turmeric, and maize emerged as the most agro-climatically suitable alternatives to shifting cultivation across three highland zones in southern China, consistently scoring above the viability threshold of 65 on a 100-point index. Field validation confirmed the rankings, with ginger producing the highest net economic returns over 14-fold greater than the shifting cultivation baseline. The multi-criteria suitability index showed a strong correlation ($r = 0.91$) with actual field performance, supporting its use as a planning tool for land use transitions in shifting cultivation regions.

A practical transition pathway would start with maize (low investment, quick returns) and progressively introduce ginger and turmeric as farmers build capital and skills. Integrating legume cover crops between main crop cycles would maintain soil health without requiring fallow periods. Extending this analysis to include socioeconomic variables, supply chain infrastructure, and participatory farmer testing across a broader geographic range would strengthen the evidence base for policy-level recommendations on shifting cultivation reform.

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