

Review

JHUM CULTIVATION IN ARUNACHAL PRADESH, NORTHEAST INDIA: A REVIEW

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HIGHLIGHTS

- Soil erosion and the loss of biodiversity rise.
- The jhum system maintains high agrobiodiversity.
- Enough fallow time is important for nature to recover.
- Agroforestry can offer ways to achieve sustainable hill agriculture.

GRAPHICAL ABSTRACT

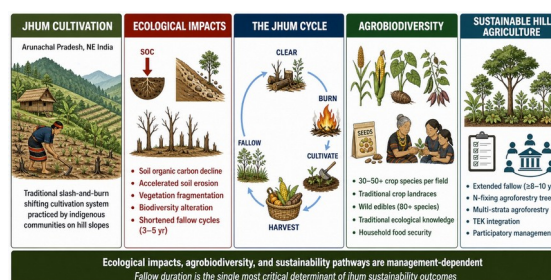


Figure 1. A graphical abstract giving a five-panel summary of jhum (shifting cultivation) in Arunachal Pradesh, in Northeast India, which is divided into three analytical themes: (i) the ecological effects such as soil degradation, erosion and loss of biodiversity; (ii) the agrobiodiversity aspects involving crop landraces, wild edibles and traditional ecological knowledge; and (iii) the routes to sustainable hill agriculture by means of integrating agroforestry and managing fallow periods.

ABSTRACT

Jhum cultivation, or shifting and swidden cultivation, is one of the oldest forms of traditional agriculture used by the indigenous peoples of Northeast India. In Arunachal Pradesh, land-use practices are strongly influenced by the region's mountainous landscape, high rainfall, vast forest areas and the variety of tribal cultures, and as a result jhum still holds ecological, agricultural, economic and socio-cultural importance. The method has on many occasions been linked to deforestation, soil erosion, nutrient depletion, a loss of soil organic carbon, changes in vegetation and a decline in productivity, especially in cases where the pressure of land use leads to shorter traditional fallow periods. Nevertheless, seeing jhum only as an environmentally harmful practice fails to take into account some of the key features of the traditional system. Important positive aspects include mixed cropping, the preservation of crop landraces, a low reliance on synthetic agrochemicals, household food production, the use of locally adapted crops, ecological recovery brought about by the fallow period, and the retention of traditional ecological knowledge. Research carried out in Arunachal

Pradesh has demonstrated a high level of crop diversity in jhum systems and that soil characteristics which deteriorate during cultivation can partly recover during the fallow phase. This review carefully looks at the ecological effects, the agrobiodiversity aspects, and the ways towards sustainable hill agriculture connected with jhum cultivation in Arunachal Pradesh and in Northeast India. By means of a narrative integrative review we have brought together published research and pertinent literature on soil properties, biodiversity, crop diversity, traditional ecological knowledge, livelihood functions and sustainability. The evidence indicates that the main ecological issue is not merely the fact that jhum exists, but rather the intensification resulting from shorter fallow cycles, repeated burning and the cultivation of steep slopes. Instead of giving up jhum altogether, a comprehensive strategy that integrates indigenous knowledge with ecologically suitable fallows, agroforestry, soil and water conservation, better fallow management, and appropriate livelihood diversification could provide a more practical path to sustainable hill agriculture in Arunachal Pradesh.

KEYWORDS: Jhum cultivation Arunachal Pradesh ecological impacts agrobiodiversity sustainable hill agriculture.

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Published by JournalsKart – Jawaharlal Nehru College Multidisciplinary Research Journal, Vol. 1, Issue No. 1, Jul–Sept 2026.

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1. INTRODUCTION

Shifting cultivation is one of the oldest agricultural systems for using land and is carried out in tropical and subtropical areas of Asia, Africa, and Latin America. Around 200 million people around the world practise it, mainly in hilly and upland forested areas (Bhardwaj, 2024; Tomar et al., 2012). In Northeast India the practice is known as jhum cultivation and is an important part of the cultural traditions of over 50 indigenous groups in the hill and valley areas of the region (Shimrah et al., 2015; Swami, 2018). It consists of a sequence in which vegetation is cleared, a controlled burning is carried out, mixed cropping is done, the crop is harvested and the cultivated land is then left to lie fallow, during which time ecological succession takes place.

Arunachal Pradesh, because of its mountainous landscape, high annual rainfall, vast natural forests and rich ethnic diversity, is one of the most important areas for jhum cultivation in India. The state includes 26 major tribes and more than 100 sub-tribes, a number of whom have in the past relied on jhum as their main method of producing subsistence food (Tangjang, 2009; Tage, 2024). Jhum in Arunachal Pradesh must be seen not just as a technique for growing crops but as an essential part of a broader social-ecological system which includes the land, the forests, water, community institutions, traditional knowledge and cultural identity (Payum et al., 2021; Bhagawati et al., 2015).

Previous interpretations of jhum have concentrated on worries regarding deforestation and land degradation. When vegetation is cleared and set on fire on steep slopes in areas with high rainfall, this can speed up surface erosion, cause a loss of nutrients, and lead to a decrease in soil organic carbon (Pathak et al., 2023; Khan et al., 2024). In several parts of Northeast India the problems have been made worse because of the shortening of traditional fallow periods due to population pressure, land fragmentation, and competing land uses (Mandal & Lonchung, 2023; Lungmuana et al., 2018). For this reason, those who criticise jhum have called for it to be replaced by settled agriculture, horticulture, or plantation systems.

Yet current ecological research paints a more nuanced picture. Traditional jhum systems which have sufficiently long fallow periods are quite

different from those intensified systems that involve repeated short-cycle cultivation. While in the fallow phase secondary vegetation successively recolonizes the cleared areas, organic matter builds up gradually, the soil microbial biomass recovers and a number of the soil's physicochemical properties are improved (Sarkar et al., 2015; Lungmuana et al., 2017; Gogoi et al., 2020). Moreover, the agricultural part of jhum often preserves a high level of agrobiodiversity, together with local landraces and traditional crop varieties which contribute to household food and nutritional security (Pandey et al., 2022; Myllemngap, 2023).

The pressures leading to intensification constitute a real and increasing danger to the sustainability of jhum in Arunachal Pradesh. In many areas the fallow periods, which used to last between 10 and 20 years, have been reduced by demographic growth, changes in land use, government resettlement schemes, and market integration to as short as 2 to 5 years in certain places (Pattanaaik et al., 2016; Bhardwaj, 2024). This greater intensity disrupts the ecosystem's basic logical structure and may result in cumulative deterioration of both soil and vegetation resources. Moreover, general policy measures which aim at eliminating jhum without providing adequate alternative sources of livelihood put household food security, cultural sustainability, and the preservation of traditional agricultural knowledge at risk (Prakash, 2018; Natori et al., 2023).

The review looks at the ecological effects, the aspects of agrobiodiversity, and the ways in which sustainable hill agriculture can be achieved in relation to jhum cultivation in Arunachal Pradesh, using as a basis peer-reviewed scientific literature, review articles and relevant research carried out by institutions. Its specific aims are: (i) to bring together the evidence regarding the ecological impacts of jhum, covering soil and nutrient dynamics, vegetation recovery, and biodiversity results throughout the fallow chronosequences and different land-use systems in Arunachal Pradesh and in Northeast India; (ii) to record the agrobiodiversity features of jhum systems, such as crop diversity, mixed cropping practices, traditional ecological knowledge, and the way in which they contribute to household food security and ecological resilience; and (iii) to assess the evidence-based pathways and interventions that could lead to sustainable hill

agriculture in Arunachal Pradesh, including the integration of agroforestry, improved fallow management, soil and water conservation, and various livelihood diversification strategies.

2. LITERATURE REVIEW

2.1 The historical background and global distribution of shifting cultivation

Shifting cultivation covers a wide variety of agricultural methods in different agro-ecological and cultural environments all over the world. It is the main system of land use in upland areas among communities in tropical Asia, Africa, and Latin America. In India it has been recorded in the northeastern states, Odisha, Madhya Pradesh, Jharkhand, and the Andaman and Nicobar Islands, although the northeast has the greatest total area and the highest cultural diversity of these practices (Tomar et al., 2012; Swami, 2018). In Arunachal Pradesh alone, almost all the tribes who live in the hills have in the past carried out jhum cultivation in all kinds of ecological zones, ranging from the subtropical foothills to the temperate montane regions (Tangjang, 2009; Bhagawati et al., 2015).

The jhum cycle, which traditionally lasted between 10 and 20 years, provided enough fallow time for vegetation and soil to recover. Yet, since the middle of the twentieth century various pressures have gradually led to shorter fallow periods in Northeast India (Bhardwaj, 2024). Prakash (2018) examined the social and economic aspects of this change and pointed out that shorter fallow periods do not only have an impact on ecological sustainability but also result in modifications to traditional community structures and the traditional practices connected with jhum. According to Tomar et al. (2012), jhum cultivation affects more than 600,000 hectares in Northeast India, the area being cultivated changing each year as the communities rotate their plots.

2.2 The dynamics of soil and nutrients in the context of jhum cultivation

The soil conditions in jhum plots undergo dynamic changes as a result of the cultivation–fallow cycle. When the land is cleared and set on fire, the vegetation biomass turns into ash, releasing minerals and causing a temporary increase in the levels of base cations such as potassium, calcium, and magnesium (Lungmuana et al., 2018; Bhagawati et al., 2015). It is this pulse of nutrients from the ash which accounts

for the relatively productive crops that are grown in the first year after burning. Yet this advantage is only temporary since subsequent rainfall events quickly wash away these readily soluble nutrients and the absence of protective vegetation on steep slopes also speeds up physical erosion (Khan et al., 2024; Mandal & Lonchung, 2023).

Soil organic carbon (SOC) is one of the most sensitive indicators of the changes caused by jhum. Pathak and colleagues (2023) showed that SOC concentrations decrease significantly in areas where jhum is being carried out as compared with those in adjacent natural forests in the heterogeneous hill regions of Arunachal Pradesh. Likewise, Kumar and co-authors (2024) recorded a reduction in SOC in jhum plots when compared with mature forest soils in that state. Lungmuana et al. (2018) looked at the soil carbon stocks after burning in the northeastern Himalayan area. They discovered that burning led to a reduction in the labile carbon fractions, which in turn affected soil biological activity and the soil's long-term capacity for carbon storage.

The duration of the fallow period is a key factor in the recovery of soil organic carbon. Sarkar and colleagues (2015) examined a fallow chronosequence in Northeast India and discovered that longer fallow periods resulted in a greater conservation of and a gradual restoration of soil organic carbon when compared with plots that had been recently cultivated. In a similar way, Nath and co-authors (2021) recorded an increase in ecosystem carbon storage and in the lability of soil organic carbon as the fallow age increased, this being associated with the progressive accumulation of tree biomass and the turnover of fine roots. Thachunglura and others (2023) looked at soil organic carbon levels on current jhum plots and on jhum fallows in Mizoram and found the pattern of progressive carbon recovery in older fallows.

Microbial biomass carbon and soil enzyme activity are closely related to the dynamics of soil organic carbon. Lungmuana et al. (2017) showed that the amounts of soil microbial biomass carbon and enzyme activity in the shifting cultivation plots in the northeastern hill area were significantly smaller than in natural forest and increased step by step as the fallow age grew. Arunachalam and Pandey (2003) recorded the changes in microbial carbon and nitrogen along successional gradients in jhum

fallows in northeast India, observing that microbial communities recovered at longer fallow ages, although the rate of recovery varied with altitude. Leindah (2013) stated that the fallow cycles in Manipur had a considerable effect on soil fertility, with longer fallow periods leading to higher levels of soil nitrogen, phosphorus and potassium. Kalidas-Singh et al. (2021) compared traditional shifting cultivation with that based on alder. They found that the alder-integrated systems kept soil fertility higher over all fallow lengths, indicating that nitrogen-fixing tree species could speed up the recovery process.

2.3 Vegetation dynamics and biodiversity

In the jhum landscapes vegetation changes are the result of two opposing processes: the loss of mature-forest vegetation when the land is cleared and a gradual recovery that takes place during the fallow period. The act of clearing initially causes a considerable decrease in tree diversity and in the complexity of the forest structure, resulting in the loss of species that depend on mature forests, such as understory plants, epiphytes, and forest-interior animals (Yakang & Nimasow, 2022; Nath et al., 2023). On the other hand, during the fallow phase, secondary succession slowly reconstructs the vegetation structure, species richness, and biomass.

Tripathi and colleagues in 2015 recorded the changes in vegetation as the jhum fallows recovered in a subtropical evergreen forest ecosystem in Northeast India, revealing that both the composition of plant species and the structural complexity increased considerably as the length of the fallow increased. Yet, differences from mature forest still existed even after a long fallow period. Gogoi and co-authors in 2020 looked at the recovery of vegetation and ecosystem carbon in the Mizoram-Manipur-Kachin rainforest region. They found that ecosystem carbon stocks had recovered to some extent, but were still significantly different from those in natural forests even in the case of older fallows, which shows how important it is to minimise both the geographical extent and the frequency of clearing.

Nath and colleagues in 2021 showed that as the length of fallow increased in jhum fallows in Northeast India, tree diversity also increased progressively and that this was positively correlated with ecosystem carbon storage. Moreover, Nath and colleagues in 2023 found that the recalcitrant soil

carbon fractions likewise recovered along the fallow chronosequences. Yakang and Nimasow (2022) noted differences in vegetation cover, soil properties, and arbuscular mycorrhizal fungal communities between jhum fallows and natural forest in Arunachal Pradesh, thus confirming that even mature jhum fallows differ from the forests they have replaced in a number of ecological characteristics.

A key point when evaluating biodiversity is the difference between the biodiversity found in natural forests and that in agricultural or agroecosystems. Although a jhum field can have a large number of cultivated plant species, landraces, and other associated organisms, it at the same time shows lower diversity among mature forest trees and less habitat complexity than the forest it has replaced. Biodiversity impact assessments have to indicate which biodiversity component is being considered, the spatial scale, and the stage of the jhum–fallow cycle.

2.4 Crop variety and agrobiodiversity

One of the most notable and ecologically important characteristics of traditional jhum cultivation is mixed cropping; a single jhum field can at the same time include cereals, millets, pulses, root and tuber crops, oilseeds, vegetables, spices, fruits and medicinal or multipurpose plants, all of which are sown and managed either simultaneously or in a complementary succession within the same area (Payum et al., 2021; Wangpan & Tangjang, 2015).

In their 2021 study of jhum cultivation in the Upper Siang District of Arunachal Pradesh, Payum and colleagues recorded a total of 43 different crop varieties belonging to various functional groups, such as food crops, condiments, fibers, fodder and plants that have medicinal uses. This example shows that jhum fields serve not only as systems for producing rice but also as diversified platforms for household food production, thus being able to offer a range of nutrients throughout the year from a single plot. The fact that there are so many locally adapted landraces within jhum systems indicates that this represents an important agricultural genetic resource which could be lost should these systems be replaced by simplified monocultures without first having been properly documented.

Wangpan and Tangjang in 2015 recorded the importance of mixed cropping in the jhum-based

traditional agroforestry systems of the Tirap and Longding districts in Arunachal Pradesh, pointing out that the different plants grown together show the result of generations of farmer knowledge concerning complementary nutrient cycling, pest control, and the availability of food at different times of the year. Pandey and colleagues in 2022 examined the biodiversity of the jhum landscape in the West Garo Hills area of Meghalaya; they found that these jhum landscapes support a wide variety of crop species, wild edible plants, and the other organisms within the agroecosystem, thus contributing to the regional agrobiodiversity. Myllemngap (2023) looked at agrobiodiversity and natural resource management in traditional agricultural systems throughout Northeast India and emphasized the role these systems play in preserving genetic diversity in cultivated plants and the associated traditional knowledge.

The possibility that agrobiodiversity could be lost as a result of giving up jhum or replacing it with other systems is a matter which deserves to be taken into account when preparing conservation and development plans. Bhagawati and others (2015) pointed out that the practice of crop diversification associated with jhum does not only help to ensure food security but also gives resilience against crop failure because different species react in different ways to changes in weather, pressure from pests, and other unforeseen events. When assessing the overall sustainability of the jhum system it is necessary to take into account this ecological insurance role of mixed cropping.

2.5 Traditional Ecological Knowledge and the Socio-Cultural Aspects

The practice of jhum cultivation represents a refined body of traditional ecological knowledge (TEK) which has been built up over many generations through the interactions between local communities and their natural surroundings. This knowledge includes the choice of suitable areas for cultivation according to the kind of soil, the existing vegetation, the slope and the drainage; deciding when to cut down and burn the land in relation to the seasonal rainfall; selecting the right combination of crops; preserving and exchanging seeds; carrying out control of weeds and pests; managing the fallow periods; and identifying the signs that the soil is recovering (Tage, 2024; Natori et al., 2023).

Tangjang in 2009 recorded traditional slash-and-burn agriculture among the Nocte people of Arunachal Pradesh as an ancient method of land use which shows a refined understanding of the environment suited to the ecological conditions of the eastern Himalayan foothills. Prakash in 2018 looked at the social aspects of shifting cultivation in north-east India and stressed that jhum is a shared knowledge system across cultures and not merely an agricultural technique, pointing out that initiatives which disregard the social and cultural aspects are generally less effective.

Natori and colleagues in 2023 looked at the various traditional methods of regenerative agriculture in India and Thailand, noting that jhum farming is one of the systems which applies regenerative ecological principles by means of fallow-based recovery, the use of minimal external inputs, and the preservation of biological diversity. The authors warned against systematically replacing these systems without first having a thorough understanding of their ecological functionality. Tage (2024) recorded the traditional techniques for land and agricultural management in the East Siang District of Arunachal Pradesh, the practices involving water management, slope stabilization, and the maintenance of crop varieties being associated with jhum landscapes.

2.6 The dynamics of fallow land and ecological recovery

The ecologically most important part of the traditional jhum system is the fallow phase. While the land is left fallow, three closely linked processes take place at the same time: vegetation succession re-establishes the forest cover and biomass; soil organic matter builds up as a result of litterfall, root turnover and microbial activity; and the soil biological communities, such as fungi, bacteria, earthworms and other invertebrates, recover step by step (Sarkar et al., 2015; Lungmuana et al., 2017).

The length of fallow needed for significant ecological recovery depends on the type of soil, the climate, the original vegetation, and the kind and length of previous cultivation. Evidence from Northeast India shows that soil microbial biomass carbon starts to recover in a measurable way after 3 to 5 years of fallow (Lungmuana et al., 2017), whereas full recovery of soil organic carbon and vegetation structure to levels close to those of the forest may take 15 to 20 years or more (Nath et al.,

2021; Sarkar et al., 2015). In practice, fallow periods have been shortened to 3 to 7 years in many regions, a duration that is not long enough to allow complete recovery of either soil or vegetation properties.

Arunachalam and Pandey, in their 2003 study, looked at the recovery of microbial carbon and nitrogen in jhum fallows situated along both altitudinal and successional gradients in Northeast India and found that both the microbial biomass and the microbial nitrogen increased significantly as the fallow age increased and were affected by altitude, higher-elevation fallows progressing along different paths of restoration than those in the lowland areas. Tripathi and others, in their 2015 research, recorded the course of vegetation succession over several years in jhum fallows within a subtropical evergreen forest and discovered that there were progressive increases in species diversity, basal area, and aboveground biomass, with the indicator species of the mature forest becoming more common in the older fallows.

Nath and others in 2023 found that the recalcitrant carbon fractions of the soil, which are significant for long-term soil fertility, also show a gradual recovery as the fallow age increases. The possibility of using fast-growing native species, such as bamboos, as a means of improving the quality of fallow has been investigated as a way to speed up ecological recovery in jhum areas, thereby giving communities extra biomass, soil protection, and non-timber forest products during the fallow period (Bhardwaj, 2024).

2.7 Policy systems, alternative forms of agroforestry and interventions aimed at sustainability

In the past, Indian policy on shifting cultivation has fluctuated between attempts to get rid of it and more recent ones which recognise its traditional and subsistence roles while at the same time trying to improve its sustainability. Programs carried out by the central government, such as the Integrated Shifting Cultivation Development Program, and various initiatives in Arunachal Pradesh have encouraged settled farming, horticulture, and agroforestry as alternatives (Tomar et al., 2012; Mandal & Lonchung, 2023).

Pattanaik and others in 2016 looked at the shift from traditional jhum to settled farming in Arunachal Pradesh. They observed that although some

households had managed to make the transition to settled farming, a number of them still kept jhum as a supplement to other livelihood activities, especially in areas having limited access to markets, irrigation, and land certification. The authors stressed that assistance aimed at facilitating the transition should take into account the entire livelihood system, not merely the agricultural aspect.

Agroforestry provides scientifically backed methods by which it is possible to move from simple extractive shifting cultivation to a form of land use that is both more productive and more environmentally stable. Shimrah and others (2015) looked at strategies for achieving sustainable agroecosystems in Northeast India and found that the use of multipurpose tree species to improve fallow management, the implementation of soil and water conservation measures based on contour lines, and the integration of horticultural species that are oriented towards market demands were some of the most promising measures. Moreover, Kalidas-Singh and colleagues (2021) demonstrated that shifting cultivation systems based on alder and featuring different fallow lengths had significantly greater soil fertility than traditional systems, indicating that incorporating nitrogen-fixing trees into the fallow plots could greatly speed up the recovery of fertility.

Modak and colleagues in 2024 looked at traditional farming methods in Northeast India from the point of view of soil and water conservation and nutrient management, pointing out that these local practices already include a number of principles that are in line with conservation agriculture, such as maintaining soil cover, growing a variety of crops, and reducing tillage. The authors advocated for a research programme that is based on these indigenous practices rather than completely replacing them with technologies coming from outside. Bhardwaj (2024) stressed that it is necessary to adopt a moderate approach which takes into account both the ecological risks and the socio-cultural importance of jhum if effective and fair land-use policies are to be developed in Northeast India.

3. MATERIALS AND METHODS

This study was set up as a narrative integrative review focusing on the ecological effects, the aspects of agrobiodiversity, and the various pathways leading to sustainable hill farming linked to jhum

cultivation, with a special focus on Arunachal Pradesh and supporting evidence from the Northeast region of India. We took into account published research articles, review papers, and relevant institutional literature concerning shifting cultivation, soil characteristics, crop diversity, biodiversity, traditional ecological knowledge, livelihoods, fallow dynamics, and sustainable land management. A time limit was not imposed and all pertinent peer-reviewed publications were included. We used non-peer-reviewed grey literature only in those cases where institutional reports or government documents offered contextual information that was not available in the primary literature.

We used thematic search combinations such as 'jhum cultivation' and 'Arunachal Pradesh', 'shifting cultivation' and 'Northeast India', 'jhum' and 'soil', 'jhum' and 'crop diversity', 'shifting cultivation' and 'biodiversity', 'jhum' and 'traditional ecological knowledge', 'shifting cultivation' and 'fallow dynamics', 'jhum' and 'soil organic carbon', and 'jhum' and 'sustainable agriculture'. The databases that were searched were SciSpace, Google Scholar, PubMed, and Mendeley; we placed a greater emphasis on peer-reviewed studies that were directly concerned with Arunachal Pradesh or Northeast India.

The information was divided into five themes: (1) soil and nutrient dynamics; (2) vegetation, biodiversity and ecological recovery; (3) crop diversity and food production; (4) livelihoods and socio-cultural functions; and (5) sustainability, fallow management and future interventions. The evidence was then grouped into positive attributes, negative consequences and outcomes that depended on management. Since the studies varied greatly in terms of location, methodology and the variables that were measured, a quantitative meta-analysis was not carried out; instead, a qualitative synthesis was applied throughout.

Figure 2. Narrative Integrative Review Methodology Flowchart

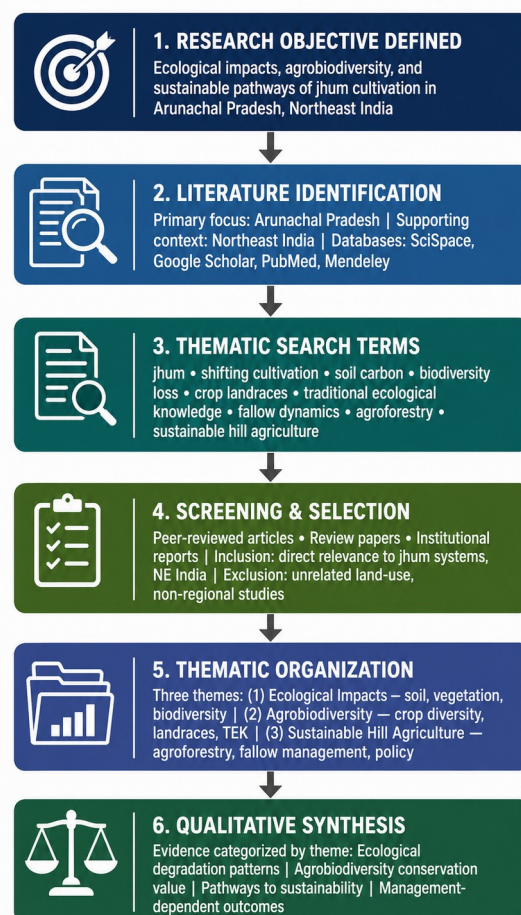


Figure 2. Flowchart showing the flowchart of the narrative integrative review methodology, outlining the six-step procedure employed to identify, screen, and thematically arrange the literature relating to three areas of analysis: (i) the ecological effects of jhum cultivation, (ii) the agrobiodiversity aspects of jhum systems, and (iii) the pathways leading to sustainable hill agriculture in Arunachal Pradesh, in the northeast of India.

4. RESULTS AND FINDINGS

A review of the existing literature has shown that jhum cultivation in Arunachal Pradesh can be understood in terms of three closely related thematic areas: (i) its ecological effects, which include soil degradation, erosion, and changes in vegetation; (ii) its agrobiodiversity features, such as polyculture diversity, traditional crop landraces, wild edibles, and traditional ecological knowledge; and (iii) the various routes to achieving sustainable hill agriculture through the management of fallow land, agroforestry, and the integration of policy.

4.1 The ecological effects of jhum cultivation

The forest clearings used for jhum cultivation result in substantial loss of vegetation and cause habitat fragmentation in Arunachal Pradesh. According to

Roy and Singh (2024), there is a gradual process of forest fragmentation in areas where shifting cultivation takes place, and the course of vegetation regeneration is greatly influenced by the length of the fallow period and the intensity of previous disturbances. Analysis based on satellite data indicates that fallow cycles which have been shortened—currently ranging from 3 to 5 years instead of the traditional optimum of 10 to 15 years—hinder the regeneration of secondary forests, decrease canopy coverage, and lead to changes in species composition that last over several cultivation cycles.

The most serious ecological effects of reducing the length of jhum cycles are soil erosion and the loss of nutrients. Saha and others in 2024 measured the amounts of soil erosion and nutrient loss on steep slopes in Northeast India and found that when the fallow period is less than seven years the rates of erosion on slopes greater than 30% are two to three times above the sustainable limits. Losses of nitrogen and phosphorus were especially bad during the first rainy season after burning, which had the effect of reducing the long-term productivity of the soil and leading to a greater need for external nutrient inputs.

The way in which soil organic carbon (SOC) changes in the context of jhum reflects the connection between burning, the regeneration of fallow land, and the level of cultivation. Kalita and others (2023) carried out a chronosequence study in districts on the border between Assam and Arunachal Pradesh and discovered that SOC stocks in fields which had recently been burned drop sharply when compared with those in mature fallow and primary forest areas. It takes fallow periods of at least 10 years for SOC to recover to the levels it had before clearing, highlighting the ecological cost of the shortened rotation periods that are now common in the jhum landscapes of Arunachal Pradesh.

Even though there are these pressures leading to degradation, the fallow periods provide important ecological services which in part make up for the effects of cultivation. During sufficient fallow periods, nitrogen-fixing pioneer species, the decomposition of litter, and the recovery of soil biota help to restore both soil fertility and structure. Lungmuana et al. (2018) found that the secondary vegetation that develops during fallow accumulates biomass quickly and thus contributes to nutrient

cycling and erosion control. Nevertheless, these ecological benefits of fallow depend on the length of the fallow and are seriously weakened when the 3-to-5 year cycles currently prevalent in Arunachal Pradesh are followed, so that management of fallow becomes the most important means of achieving ecological recovery.

4.2 The dimensions of agrobiodiversity in jhum systems

The jhum fields in Arunachal Pradesh are one of the most species-rich forms of agricultural practice in South Asia, involving the growing of 30 to 50 or more kinds of crop in each field. Seidler et al. (2026) recorded the crop diversity in polyculture within jhum fields in Northeast India and found that the high level of functional diversity and conservation value is due to the continued presence of locally adapted landraces, which are largely missing from market-driven monoculture systems. The fact that crops are grown in this polyculture arrangement helps to mitigate pest outbreaks, moderates the local microclimate, and spreads out the demand for labour over the course of the agricultural year.

The level of food security among families in areas where jhum farming is practiced is closely linked to crop diversity and the dependability of harvests from a variety of crops. Saikanth and others (2023) carried out a survey of jhum farming households in Nagaland and Manipur and discovered that the crop diversity indices were positively associated with the nutritional diversity scores, and that households managing more than 20 different crop species per field had a significantly lower rate of experiencing seasonal food insecurity. In Arunachal Pradesh too, the same trends are observed, jhum fields acting as the main source of vegetables, legumes, cereals and medicinal plants for subsistence communities.

The cognitive and cultural foundation of jhum agrobiodiversity is traditional ecological knowledge (TEK). According to Jeengaph (2023), who looked at the transmission of TEK in Northeast India, the intergenerational knowledge of crop varieties, intercropping patterns, phenological signs, and fallow indicators is mostly passed on through hands-on experience on jhum fields. This knowledge encompasses the specific planting densities for different species, combinations of companion crops that are suited to the local soils, and the ability to identify indicator species which signal that the land

is ready for fallow—knowledge which cannot be substituted by external agronomic recommendations and which therefore represents a form of biocultural heritage.

The wild edible plants and the traditional crop landraces found in jhum fields play a major role in ensuring nutritional security and in the conservation of genetic diversity. In their study of edible plants linked to jhum agroecosystems in Arunachal Pradesh, Nath et al. (2023) recorded more than 80 species that are used as vegetables, condiments, and food supplements, a number of which are found only in the jhum fallows and along the edges of the fields. These wild edible species help to alleviate dietary shortages that occur at different times of the year and act as a storehouse of genetic variability—including genes from the wild relatives of cultivated species—conservation of which relies on the continued existence of jhum agroecosystems and the traditional ecological knowledge (TEK) systems that regulate their use.

4.3 Routes to sustainable hill agriculture

The literature states that the management of fallow duration is the most important measure for maintaining jhum agroecosystems. Kamei (2025) examined the fallow threshold requirements and long-term changes in land cover in the districts of Nagaland that rely on jhum, finding that fallow periods of 8 to 10 years are necessary if soil fertility, above-ground biomass, and species diversity are to be restored to levels that allow for productive cultivation. Policy approaches which promote longer fallow periods—by ensuring land tenure security, providing alternative livelihoods during the fallow years, and establishing community-based agreements for fallow management—are thus essential to achieving sustainable hill agriculture in Arunachal Pradesh.

There is a biological approach, involving nitrogen-fixing trees and better fallow species, which can be put into practice in order to speed up the recovery of soil fertility and decrease the length of time that fallow periods need to last. Bharadwaj and colleagues (2024) looked at agroforestry systems that included nitrogen-fixing species in jhum fallows throughout Northeast India and discovered that soil nitrogen availability, microbial biomass carbon, and crop yields in the next growing phases all improved considerably. In Arunachal Pradesh, species like

Tephrosia candida, *Sesbania sesban*, and *Flemingia macrophylla* have been successfully used as improved fallow species in jhum fallows, alleviating nutrient limitations without the need for chemical fertilisers.

Multi-strata agroforestry systems provide the most structurally complete means of moving jhum landscapes towards sustainable hill agriculture. Hazarika et al. (2024) showed that multi-strata agroforestry not only results in higher carbon stocks but also brings about greater economic returns compared with traditional jhum in the landscapes on the border of Assam and Arunachal Pradesh. Gurung and Phuntso (2025) found that community-managed agroforestry lessens the pressure on shorter fallow cycles by offering a source of income throughout the year from timber, fruit, and non-timber forest products. Furthermore, Wonglangka et al. (2025) stressed that agroforestry systems which are designed with the involvement of farmers and include the integration of traditional ecological knowledge perform better than those designed externally in terms of biodiversity outcomes and long-term adoption rates, highlighting the importance of participatory methods in the shift to sustainable hill agriculture.

Table 1. A summary of the main ecological impacts, agrobiodiversity features, and sustainable pathways for hill agriculture that have been recorded within the jhum cultivation systems of Arunachal Pradesh and Northeast India.

Dimension	Positive Aspect	Negative Aspect / Risk
Crop production	Multiple crops and local varieties; diversified food basket	Variable or low yield of individual staple crops
Agrobiodiversity	High crop species and landrace diversity within plots	Loss of mature-forest habitat and associated biodiversity
Soil fertility	Fallow enables partial recovery of SOC and nutrients	Erosion, carbon and nutrient loss during active cultivation
Nutrient management	Ash provides short-term mineral nutrients post-burn	Burning causes nitrogen and sulfur volatilization; nutrient leaching
Agrochemical inputs	Traditionally low dependence on synthetic inputs	Nutrient replenishment may be inadequate under short fallows

Dimension	Positive Aspect	Negative Aspect / Risk
Livelihood	Supports subsistence and household food security	Labour-intensive; limited cash income in many settings
Culture and knowledge	Preserves indigenous TEK across generations	TEK may decline with socioeconomic change and migration
Fallow ecology	Promotes vegetation succession and carbon recovery	Short fallows cause incomplete recovery; degradation feedback
Genetic resources	Conserves traditional crop landraces in situ	Landraces may disappear as farming systems are replaced

5. DISCUSSION

The review brings together evidence along three thematic lines—ecological effects, agrobiodiversity, and sustainability pathways—in order to provide a full evaluation of jhum cultivation in Arunachal Pradesh in northeast India. The results indicate that jhum is not everywhere damaging and not everywhere beneficial; its ecological and socio-economic effects are heavily influenced by the length of the fallow period, the level of cultivation intensity, and the particular landscape setting. It is necessary to understand this complexity, which depends on the way it is managed, if policy and management measures are to be developed that keep the advantages of jhum while reducing its negative ecological effects.

The review's assessment of the ecological impact shows that the main cause of environmental deterioration in jhum areas is the reduction of fallow periods. When the length of fallow is less than the ecologically acceptable limit of 8 to 10 years, there is a decline in soil organic carbon (Kalita et al., 2023), faster soil erosion (Saha et al., 2024), and poor vegetation recovery (Roy & Singh, 2024). This is in agreement with wider global evidence concerning the intensification of shifting cultivation and highlights the urgent need for fallow management policies which restore ecological function to jhum areas. The ecological benefits provided by sufficient fallow periods—namely, the accumulation of soil organic carbon, the control of erosion, and the recovery of plant species—prove that jhum can be

ecologically self-correcting if fallow cycles are kept at their traditional lengths.

The aspect of agrobiodiversity shows that jhum systems act as repositories of significant biological and cultural diversity. The variety of crops grown in polyculture (Seidler et al., 2026), traditional crop landraces, wild edible plants (Nath et al., 2023), and traditional ecological knowledge (Jeengaph, 2023) together form an agrobiodiversity complex which supports food security, nutritional diversity, and genetic conservation. The agrobiodiversity in question, nevertheless, is being hit by a number of threats resulting from agricultural intensification, demographic change, and the loss of the channels through which TEK is passed on. If jhum agrobiodiversity is to be conserved it is necessary to give it explicit recognition in both biodiversity and agricultural policy frameworks, going beyond an exclusively ecological viewpoint to include the biocultural aspects of jhum knowledge systems.

The set of interventions outlined in the sustainability pathways dimension—namely fallow threshold management, the integration of nitrogen-fixing trees, and multi-strata agroforestry—can address both the ecological and the livelihood aspects of jhum cultivation. Together, Kamei (2025), Bharadwaj et al. (2024), Hazarika et al. (2024), Gurung and Phuntso (2025), and Wonglangka et al. (2025) show that these interventions are ecologically effective and economically viable. The best chances of adoption occur when the interventions are designed in a participatory manner with the communities that depend on jhum and are based on existing TEK frameworks, not when they are introduced as part of externally prescribed agricultural modernization pathways.

The recognition by both land tenure systems and policy of jhum as a valid form of land use allows all the sustainability options identified in this review to be achieved. When jhum practitioners do not have secure rights to the land, the incentives needed for long-term fallow management and for investing in agroforestry are seriously weakened. Payum et al. (2021) and Prakash (2018) point out the governance aspects of jhum sustainability, observing that community-based systems for the management of natural resources, which are part of traditional institutions, have in the past kept jhum cycles ecologically viable. It is essential to strengthen these

institutions—rather than replace them with external regulatory systems—in order to achieve lasting sustainability in hill agriculture in Arunachal Pradesh.

The way in which the findings discussed here are interpreted is limited by methodological factors. Studies using remote sensing to examine the length of fallow periods and changes in land cover are affected by the resolution of the images, the classification algorithms employed, and the amount of ground-truth data available in remote hill areas. Surveys carried out among households on issues of food security and the retention of traditional ecological knowledge are prone to recall bias and are constrained by the difficulties of sampling in widely scattered jhum communities. In future research, long-term monitoring plots should be given priority so as to follow soil, vegetation, and agrobiodiversity indicators throughout the entire jhum cycle, and this should be combined with participatory rural appraisal methods that enable the dynamics of TEK and livelihood outcomes to be captured at the same time, in order to produce evidence that corresponds to the complexity of jhum systems.

The significance of this review goes beyond Arunachal Pradesh and relates to wider discussions concerning shifting cultivation in the humid tropics. Northeast India is one of the last areas in which jhum is still a land-use system that is both culturally rooted and ecologically effective on a large scale. The evidence presented in this study lends support to revising the traditional 'slash-and-burn' idea which has in the past identified jhum with deforestation and degradation. Jhum may become a sustainable form of hill agriculture provided that appropriate fallow management is carried out, agroforestry is integrated and adequate policy support is given, thus helping to conserve biodiversity, ensure food security, and preserve the invaluable biocultural heritage for future generations in Arunachal Pradesh.

6. CONCLUSION

The review shows that jhum cultivation in Arunachal Pradesh in northeast India has three closely related aspects—ecological effects, agrobiodiversity, and the routes to sustainable hill agriculture—which have to be fully understood if effective policy and management actions are to be developed. Since the fallow periods are too short, ecological degradation

occurs, showing itself in a fall in soil organic carbon, increased erosion, and poor vegetation recovery; on the other hand, a sufficient fallow period allows for considerable ecological self-repair, highlighting the fact that fallow management is the basic means of achieving sustainability in jhum agroecosystems.

The polyculture diversity, traditional crop landraces, wild edible plants, and related traditional ecological knowledge contained in jhum systems form a biocultural heritage of global importance which is at present not adequately acknowledged in India's agricultural and biodiversity policy frameworks. If this agrobiodiversity is to be conserved it is necessary to carry out deliberate policy integration that sees jhum not simply as a temporary type of land use to be replaced, but as a dynamic agroecosystem deserving of research funding, institutional support, and community-based governance in order to empower the indigenous communities who practise jhum.

Possible routes to achieving sustainable hill farming in areas dependent on jhum are not only feasible but are also supported by evidence; these involve prolonging the fallow periods to ecologically sound limits, incorporating nitrogen-fixing improved fallow species, and, where appropriate, moving towards multi-layered agroforestry with the involvement of farmers and the integration of traditional ecological knowledge. Future research should focus on long-term field experiments, the use of remote sensing at the landscape level, and participatory agroecological evaluations in order to produce evidence that matches the complexity of jhum systems. If adequate investment and institutional backing are provided, the jhum landscapes in Arunachal Pradesh can act as examples of hill agriculture that is beneficial for biodiversity and ensures food security throughout the humid tropics of South and Southeast Asia.

DECLARATIONS

Conflict of Interest. The author has no conflict of interest concerning this review.

Funding. The review has not obtained any grants or funding from any agency in the public, commercial, or not-for-profit sectors.

Acknowledgements. The author would like to acknowledge the Department of Botany at Jawaharlal Nehru College in Pasighat for its institutional support

and also the research community that studies jhum cultivation and shifting agriculture in Northeast India, since it is the work published by this group that has formed the basis of the present review.

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