ECOLOGICAL ANALYSIS OF JHUM FIELDS ALONG AN EDAPHO-CLIMATIC GRADIENT OF NORTHEAST INDIA

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Submitted
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CERTIFICATE

This is to certify that the Thesis entitled *"Ecological Analysis of Jhum Fields along An Edapho-Climatic Gradient of Northeast India"* submitted by Mr. L K Thang Ngaihte for the degree of Doctor of Philosophy in Environmental Science embodies the record of original investigation carried out by him under my guidance and supervision. He has been duly registered and the Thesis presented is worthy of being considered for the award of the Ph.D. degree. This Thesis or any part thereof has not been submitted for any degree of any other University.

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I **LK THANG NGAIHTE**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
AMSL	Above Mean Sea Level
ANOVA	Analysis of variance
Avail. K	Available Potassium
Avail. N	Available Nitrogen
Avail. P	Available Phosphorus
BCR	Benefit Cost Ratio
BD	Bulk Density
Ca	Calcium
CHMR	Corrected Hydrometer Reading
DAS	Days After Sowing
DEM	Digital Elevation map
dSm^{-1}	Deci Siemens per metre
EC	Electrical Conductivity
EP	Enpum
Exch. Ca	Exchangeable Calcium
Exch. Mg	Exchangeable Magnesium
Exch. Na	Exchangeable Sodium
FAO	Food and Agriculture Organization
FSI	Forest Survey of India
GR	Green Revolution
ha	Hectares
HI	Harvest Index
HK	D. Hengkot
HMR	Hydrometer Reading
HYV	High Yielding Variety
ICAR-RC	Indian Council of Agricultural Research – Regional Centre
ICSSR	Indian Council of Social Science Research
IFAD	International Fund for Agricultural Development
IMD	India Meteorological Department

ISFR	India State of Forest Report
K	Potassium
KB	Kawlbem
KG	Khuanggin
KK	Khawkawn
LAI	Leaf Area Index
LSD	Least Significant Difference
MDG	Millenium Development Goals
Mg	Magnesium
ml	millilitre
mm	Millimetre
MZU	Mizoram University
N	Nitrogen
Na	Sodium
NE	NE Khawdungsei
NEH	North Eastern Hill
NFSM	National Food Security Mission
NGO	Non-Governmental Organization
NITI	National Institution for Transforming India
NLUP	New Land Use Policy
NPK	Nitrogen, Phosphorus, Potassium
NTFP	Non-Timber Forest Products
P	Phosphorus
ppm	Parts per millions
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goals
SEA	Southeast Asia
SEM	Standard Error of Mean
SMC	Soil Moisture Content
SOC	Soil Organic Carbon

SOM	Soil Organic Matter
SPSS	Statistical Package for Social Sciences
t/ha	Tons per hectare
TEK	Traditional Ecological Knowledge
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VPD	Vapour Pressure Deficit
WHC	Water Holding Capacity
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

Agriculture has been one of humanity's most important practices for their survival and spread on Earth, and it has played a crucial role in addressing global challenges such as hunger and poverty (Arora, 2018). It was the broadest term used to describe the diverse ways in which cash crops and native animals support the global human population by providing food and other goods (Harris & Fuller, 2014). The world population was projected to grow from about 7.2 billion then to 9.3 billion in 2050, and this population increase and expected dietary changes associated with income growth suggested that agriculture would grow 60 percent worldwide by 2050 would have to produce food. and 100 percent more in developing countries if the demand is to be met at current consumption levels (United Nations, 2013).

One agricultural practice that has sustained populations in developing regions for centuries is jhum or shifting cultivation, also known as slash-and-burn or swidden agriculture. This involves clearing small patches of land by slashing brushes and burning debris, cultivating crops on the cleared land for a few seasons, and abandoning it fallow to regenerate soil fertility (Mertz et al., 2009). Shifting cultivation is widely practiced by indigenous communities in tropical forests of Asia, Africa, and South America. For example, in northeastern India, shifting cultivation locally known as jhum cultivation is the main agricultural practice among tribal communities (Ramakrishnan, 1992). Although yields are low, shifting cultivation provides food security and maintains agrobiodiversity in marginal lands that are unsuitable for intensive agriculture (van Vliet et al., 2012).

Technical innovations and improvements in institutions have led to major advances in agricultural production and productivity. However, current food production and delivery methods are insufficient for feeding on the planet. Agriculture provides sufficient food for 12 to 14 billion people, approximately 850 million, or one in eight, of the world's population suffering from chronic hunger (FAO, 2013). The vast majority of those experiencing hunger lived in developing areas, where malnutrition rates were estimated at 14.3 percent (FAO, IFAD, & WFP, 2013). The main cause of hunger and malnutrition was not the lack of food but the inability to buy anything. In 2010, more than one-third of the rural population in developing countries was extremely poor (FAO, 2013). Disproportionately, 60 percent of the undernourished were women, who made up 43 percent of the agricultural workforce and faced pervasive discrimination in access to land and other resources and services (Asian Development Bank, 2013).

Pretty and Hine (2001) analysed the expected changes in food demand and highlighted that it would grow and change in the coming years owing to three main factors: i) a growing world population, ii) rising incomes, and iii) increasing urbanisation. They believed that factors such as technological access, knowledge, economic performance, education, and women's empowerment played crucial roles in achieving food security.

Alston & Pardey (2014) emphasised that although agriculture represented a relatively modest part of the global economy, it had enormous importance in the lives of a significant proportion of the population, particularly in middle- and low-income countries, where the majority of the population is farmers. Agriculture plays a much larger role in national income and provides a significant share of employment. They also highlighted that agriculture contributed 18% of the national income and employed 54% of the workforce in India that about 2.6 billion people worldwide depended on agriculture as their main source of income in 2010, either as active workers in the sector or as dependents. Many smallholder farmers in developing regions rely on shifting cultivation for subsistence (Arthur-Josué et al., 2020).

The United Nations approved the Sustainable Development Goals (SDGs) in 2015 with the goal of completing them by 2030.SDG 2 is concerned with eradicating hunger and guaranteeing universal food access. Prior to the SDGs, over 820 million people globally battled hunger, according to FAO (2019). Prior to the SDGs, the UN and its member states approved the United Nations Millennium Declaration, generally known as the Millennium Development Goals (MDGs), in 2000. One of the MDGs' 2015 deadline goals was to eradicate poverty and hunger.

To achieve United Nations goals, it was imperative to acknowledge the vital role of agriculture, especially among traditional farmers in developing and underdeveloped nations who rely on shifting cultivation, and to enhance agricultural production and associated techniques and systems. The adoption and improvement of traditional farming methods like jhum could form a significant part of the strategy for advancing global agricultural sustainability in alignment with the UN objectives. By recognising and supporting the pivotal role of agriculture, particularly shifting cultivation, society can make significant contributions to ecological security, food security, and the overall well-being of communities in developing and underdeveloped countries.

1.1. Jhum cultivation

In general, jhum can be defined as a farming system that involves clearing forested land for cultivation, farming it for a short period, abandoning it, and allowing natural vegetation to regenerate while clearing another plot of land.

The Food and Agriculture Organization (FAO, 1957) defined it as "the practice of cultivating temporary clearings in natural forests or grasslands and abandoning them when the soil loses fertility, which involves shifting homesteads to find new fertile land." FAO’s definition encapsulates the fundamental aspects of shifting cultivation, including the cyclical nature of land use, the relationship between soil fertility and cultivation cycles, and the mobility of homesteads in response to changing agricultural needs. This underscores the dynamic and adaptive characteristics of this agricultural system, where the land is managed in harmony with natural regeneration and ecological sustainability.

Jha (1976) stated that it can be "an alternative to permanent cultivation on mountain slopes where the latter is difficult with basic technology." He suggested that jhum cultivation can serve as a viable alternative to permanent cultivation on mountain slopes, particularly in situations where the latter is challenging due to basic or limited agricultural technology and highlighted the practicality of jhum cultivation in regions characterised by difficult terrain and limited resources.

McGrath (1987) defined it as "a resource management strategy that exploits the energy and nutrients in the vegetation-soil complex of future garden sites." He highlighted the dynamic and sustainable nature of shifting cultivation, in which natural processes within the ecosystem are tapped to support the energy and nutrient needs of garden sites in a cyclical manner.

The Forest Survey of India (FSI, 1997) described it as "cyclical cultivation where farmers clear trees, burn them, farm the land briefly, then move to a new site and repeat the process." The definition by the FSI highlighted the cyclical and mobile nature of shifting cultivation, where the land is rotated between cultivation and fallow phases, aligning with ecological and sustainable principles, and also emphasised the deliberate clearing and regeneration cycle that characterizes this form of agriculture.

Bhagawati et al. (2015) characterized it as "a traditional system involving cleared land using controlled fire and a lengthy fallow period sufficient for woody regrowth." Their definition highlights the intentional use of controlled fires in land preparation and the significance of the fallow period in supporting the regrowth of woody plants. They also depicted it as a customary practice that is deeply rooted in traditional knowledge.

Some definitions of jhum focus on agroecosystem dynamics. Shifting cultivation is seen as a flexible reaction to stress and balances the cultivation and fallow phases as part of the broader ecosystem (Altieri et al., 1983; Gliessman, 1985, 1989; McGrath, 1987). Their perspective recognised and emphasised that shifting cultivation is not just a land-use practice but a dynamic agroecosystem approach characterised by its adaptability, its cyclic pattern of cultivation and fallow, and its consideration of broader environmental and ecological dynamics.

Thrupp et al. (1997) stated that it "includes cropping systems, perennial crops, animal husbandry and forest/fallow management in rotational cycles." They found that shifting cultivation is a dynamic and multifaceted agricultural system that involves a range of activities, including crop cultivation, management of perennial crops, animal husbandry, and rotation of land use between cultivation and fallow periods.

Seavoy (1973) simply defined it as "clearing forest patches for brief cultivation before abandoning them for new patches." He offered a concise definition of shifting cultivation as the practice of clearing small forest patches for temporary cultivation before moving on to new patches. This definition succinctly captures the essence of shifting cultivation, highlighting the cyclical nature of land use, and the sequential clearing and abandonment of cultivated areas.

Warner (1991) described it as "an agricultural system well-adapted to environmental limitations in the tropics under certain conditions." Her definition acknowledged that shifting cultivation is well suited to particular tropical environments, where its cyclical and mobile nature aligns with the ecological and resource limitations often present in these regions.

Bogaard (2002) referred to it as "using newly cleared, burned woodlands for short-term cultivation followed by long regeneration periods before returning to previous plots." This definition highlights the systematic rotation and alternation of land use, where areas are cyclically cleared, farmed, and allowed to recover, contributing to the sustainable management of agricultural resources and ecosystems.

Lal (2005) defined it as "a cycle of short cultivation and long fallow periods on cleared land." This definition succinctly captures the essence of shifting cultivation, emphasising the cyclic nature of land use, where short periods of cultivation are followed by extended intervals during which the land is allowed to regenerate naturally.

Mertz (2009) specified that "the fallow phase dominated by woody regrowth is longer than cultivation and involves clearing by fire." This definition highlights the importance of a prolonged fallow period for natural regeneration and nutrient replenishment, as well as the deliberate use of controlled fires in land preparation, which are key features of shifting cultivation.

Okigbo (1984) characterized it as "an extensive system employed where farmer have abundant land and freedom to cultivate new areas as needed." This definition highlights the flexibility and mobility inherent in shifting cultivation, where the availability of ample land resources allows farmers to continually seek new areas for cultivation, reinforcing the sustainable and adaptable nature of this practice.

Teegapalli & Datta (2017) summarized it as "temporary cultivation followed by long fallow periods allowing soil fertility recovery before recurrence of cultivation on the same land." This definition highlights the cyclic and sustainable nature of shifting cultivation, where land undergoes periods of active use and rest, contributing to the long-term productivity and ecological balance of the agroecosystem.

In summary, shifting cultivation involves rotational clearing of forested land for brief cultivation, followed by abandonment and long fallow periods to allow natural woody regrowth and soil fertility restoration before subsequent recultivation. It is an extensive, traditional system well adapted to tropical ecosystems and areas with abundant land, employing fire to clear plots and integrating cropping, perennial crops, and livestock. The fallow phase sustains the ecological balance and is fundamental to replenishment. Overall, shifting cultivation is a diverse, flexible agricultural system based on managing cultivation and fallow cycles.

1.2. Origin of jhum cultivation

The transition from a hunter-gatherer lifestyle to agriculture during the Neolithic Revolution led to the rapid expansion of agricultural activities into forested areas, giving rise to shifting cultivation, a practice marked by temporal crop rotations within forest ecosystems, representing a significant milestone in agricultural history (Ducourtieux, 2015). Lal (2005) believed that jhum was the oldest agricultural system in which soil fertility was restored through long periods of fallowing rather than through off-farm application of fertilizers.

From archaeological data, the origin of jhum cultivation can be traced back to the Neolithic period (Sharma, 1976; Kumar & Biswal, 2013; NITI Aayog, 2018), which dates back to 10,000 B.C. (Thrupp et al., 1997), representing a fundamental transition in human culture from grain harvesting to food production (Sharma, 1976). Mishra (2022) called it a storehouse of both biological and cultural diversity. Conklin (1961) described it as a persistent agricultural system in which unstable clearings are cultivated for shorter periods of time than they lie fallow, whereas Gupta (2005) described it as a form of agriculture occurring primarily in tropical regions, and subtropical belts are used worldwide (Bordoloi, 1976).

Jhum or shifting cultivation is also known by various names such as rotational bush farming, swidden farming or slash-and-burn farming (Kumar & Biswal, 2013), *swidden* (Old English), *rai* (Sweden), *milpa*, *conuco*, *roza* (Latin America), *shamba*, *chitemene* (Africa), *jhum* (India), *kaingin* (Philippines), *ladang* (Indonesia and Malaysia) and many others; The fallow lands were commonly referred to as bush fallow and *jachere* in Africa. *Barbecho*, *Capoeira*, and *Purma* in Latin America; and *Belukar* and other terms in Indonesia (Sanchez & Palm, 2005), rotational farming of Karen (Northern Thailand), *Shwe Pyaung Taungya* (Myanmar), *Lunxidi* (China), *and Khoriya* (Nepal) (Shaw et al., 2022). In northeastern India, it is commonly known as *jhum*; in Orissa as *Podu*, *Dabi*, *Koman*, and *Bringa*; in Bastar as *Deppa*; in the Western Ghats as *Kumari*; and *Bewar* or *Dahia* in Madhya Pradesh (Bhowmik, 1976).

Shifting cultivation has evolved as an ecological response to the challenges of tropical climate and vegetation, and has endured because traditional farmers were able to live and feed their populations in a delicate balance with the natural environment (Kio, 1972). Denevan (1978) argued that although various factors contributed to forest destruction, such as: land clearance for food and plantation cultivation, animal husbandry, road construction, logging, fuel production and combustion, but jhum cultivation is the most important direct factor.

The shift in cultivation was a response to the challenges of creating an agroecosystem in a tropical forest, usually characterised by poor but diverse soils and extremely diverse vegetation and fauna, providing limited nutrients but many possible competitor species for food crops (Warner, 1991).

Under this system, land was gained by clearing forested areas using slash-and-burn practices. This included site selection, slash-and-burn agriculture, development, and regeneration through land abandonment (Gupta, 2000). Hauck (1973) estimated that shifting agriculture accounts for approximately 10% of the world's population.

Brady (1996) described the activities of farmers and the shift in management as they moved to another forest plot, which they burned and then farmed for two to three years before that plot was abandoned. A farmer might move to 5-10 of these small plots in turn before returning to clear and burn trees in the first plot, which was unused (fallow) 10-20 years ago. These steps were repeated until completion of another cycle.

1.3. Components of jhum

According to Conklin (1961), shifting cultivation comprises three principal components: the environment, culture, and time. The environmental aspects encompass biotic, edaphic, and climatic factors; the cultural component encompasses technological, social, and ethnological factors; and the temporal aspects include selection, cutting, pruning, and fallowing.

Jhum has been the subject of debate in the environmental and development community, which criticised shifting cultivation as a primitive, destructive or wasteful form of agriculture, and for those who viewed it as a sustainable and sedentary form of agriculture (Thrupp et al., 1997).

Some scientists believed that the practice of jhum was primitive, traditional, ecologically sensitive and destructive (Jha, 1976; Rai, 1976; Bordoloi, 1976; McGrath, 1987; Ninan, 1992) and even led to the extinction of significant fauna and flora the region (Verma et al., 2017). Bhowmik (1976) reported that jhum dried up the spring and affected rainfall in the region. Choudhury & Sundriyal (2003) observed that jhum affected forests and ecological resources, leading to soil erosion and soil depletion, and also concluded that field yields decreased significantly in areas where the jhum cycle was drastically reduced. Jain et al. (1976) found that changes in soil had a direct impact on the flora of the region. Makdo et al. (2016) observed that jhum cultivation in Arunachal Pradesh was typically associated with low crop yields and soil degradation, loss of forest richness and soil fertility.

Shifting agriculture, combined with wildfires, killed almost all climax vegetation in the southeastern region and destroyed approximately 37% of the total forest area (Khan & Khisha, 1970; Brammer, 1986). A short jhum cycle and low agricultural yields have led to severe socio-economic problems, in addition to depleting the available land, leading to the migration of farmers. The felling of trees for jhum led to the opening of the land, resulting in increased runoff, topsoil erosion, a decline in soil fertility, and low crop yields due to the lack of soil and water conservation measures during high rainfall. and downstream flooding and siltation of reservoirs (Singh & Prasad, 1976). The tools used were simple and did not use fertiliser, and irrigation systems usually consisted of machetes or axes for cutting and chopping, or sticks for digging the soil (Okibo, 1984).

1.4. Extent and characteristics of jhum cultivation

Jhum or shifting cultivation is an entire socio-cultural institution, not just a form of farming, governing the lives and livelihoods of indigenous communities across upland northeast India (Leblhuber, 2012; Rahman et al., 2011). The cyclical process of slash-and-burn agriculture reflects the ecological adaptation to local environments (Warner, 1991). Jhum regulates diverse aspects of social life from ceremonies to governance around shared forest resources, sustaining tribal populations for centuries (Conklin, 1961; Altieri et al., 1983). Deeply embedded in cultural heritage and traditional ecological knowledge, jhum is central to the identity and worldview of communities for whom it has endured as an anchor for livelihoods, health and cultural integrity (Shillong Declaration, 2004; Zothansanga & Beingachi, 2019). Hence, interventions aimed at transforming jhum must account for its sociocultural context to secure ecological sustainability and food and livelihood security for upland populations (Lebhluber & Vanlalhruaia, 2012; Vanlalchhawna, 2015).

The core idea of shifting cultivation is hunting, gathering, and growing crops that complement each other ecologically. Cutting down trees, burning the forest, cultivating the soil, planting, and harvesting are examples of how solar energy stored in the forest is converted into food energy (Yin, 2015). The shifting cultivation system was considered an initial stage of agricultural development (Saha, 1976), a primitive agricultural tradition throughout hilly terrain (Borthakur,1992) and is still practiced today. Shifting cultivation has been practiced in various regions, including the Amazon basin, southwest China, Africa, Korea, Vietnam, other neighbouring countries (Dalle & Blois, 2006), South Asia, and Southeast Asia (Sati, 2020). Conklin (1957) reported that Africa has the largest area of shifting cultivation, followed by Latin America. Other areas where jhum cultivation predominated included Sumatra, northern Burma, Borneo, and New Guinea (Bhowmik, 1976).

Lal (2005) provided an insightful characterization of the complex and variable nature of jhum cultivation systems. He described jhum as diverse agricultural practices adapted to local soil types, terrain, vegetation patterns and climatic conditions. This system integrates cropped areas with livestock rearing. Jhum cultivation is labour-intensive and relies on intrinsic soil fertility restoration through biomass recycling over prolonged fallow periods rather than external inputs. He also noted that the system remains stable and sustainable when the fallow period-to-cropping period ratio is 10 years or longer. However, it fails when fallow periods are drastically shortened, owing to rising demographic pressures and the declining availability of arable land. This has led to severe land degradation and decreased productivity. Jhum is generally practiced on small family-held plots less than two hectares in size. The multifaceted, risk-prone, and subsistence-oriented nature of jhum agriculture calls for nuanced interventions that enhance sustainability without undermining the livelihood security of indigenous communities that are dependent on traditional farming practices.

Rahman et al. (2011) examined the causes of the jhum cultivation system and found that tradition and customs played an important role in the continuation of the practice. They also found that large family sizes and lack of opportunities were other factors that played a role in jhum cultivation. Kamajou (1983) believed that shifting cultivation, like other agricultural practices, was the result of a complex interaction of environmental forces. Some were socioeconomic and physical in nature, such as land, labour, technology, and all forms of capital, while others were institutional in nature, such as cultural values, land tenure systems, social organisations, traditional and new or modern institutions, and input and output pricing policies.

Spencer (1958) classified it as a primitive subsistence farming system with the following distinctive characteristics: primitive people practiced it in small numbers by burning the waste after it had dried; frequent changing of fields from place to place, with the fields following the crops abandoned, planting various agricultural crops in the same field, use of primarily annual and short-term food crops, minimal to no soil preparation before planting, and little to no weeding, cultivating, or other maintenance; the crops grew extensively for nutrition; poor production and yield with minimal surplus; deforestation and severe soil erosion.

Since its inception, shifting cultivation has always been characterised by a change of fields and not by a rotation of crops, the use of human labour, the absence of animals and fertilisers, the use of dibble sticks or hoes, and short periods of use alternating with long fallow periods to support the regeneration of vegetation, ultimately leading to the emergence of secondary forests (NITI Aayog, 2018).

The Shillong Declaration (2004) recognized shifting cultivation as "one of the most complex and multifaceted forms of traditional agroforestry practice in the world, reflecting robust traditional ecological knowledge" and that it "evolved as a traditional practice and was an institutionalized resource management mechanism at a species, ecosystem, and landscape level, ensuring ecological security and food security, and thus providing a social safety net." A notable feature of shifting cultivation was the cultivation of a wide range of grains and vegetables in a single area, which is unusual in wetlands and may be one of the reasons why simple societies continued to adhere to this method of food production (Sharma, 1976).

Dalle & Blois (2006) described jhum as one of the most widespread types of agricultural systems in the tropics, providing not only culturally significant crops, but also medicinal, culinary, ritual, fuel, and forage resources that support livelihoods, health, and the promotion of the health of local people. and cultural identity. However, Okigbo (1984) believed that shifting agriculture developed, and that, as a result, multiple types of shifting agriculture and associated fallow systems now exist among people with different historical and cultural backgrounds in diverse environmental settings in Africa, Southeast Asia, Central and South America, and Oceania.

Shifting cultivation has been practiced across a wide variety of landscapes and habitats, including steep hill regions, flat areas, low valleys, moist tropical forests, and seasonal floodplains (Whittlesey, 1937; Rai, 1976; Sarkar, 1982; Sen, 1992; Saha et al., 2012; Sati, 2020; Thrupp et al., 1997). In the 1980s, Russell (1988) and Lanly (1985) estimated that to 300-500 million people worldwide practiced some form of shifting agriculture. Lynch (1992) reported that over 400 million people in Asia depend on forests and shifting cultivation. The global area affected by shifting cultivation was estimated to be approximately 2.9 billion hectares by Stiles (1994). However, determining the total land area affected is difficult because of the diversity of shifting cultivation practices (Thrupp, 1997). Sanchez (1976) and Hauck (1973) estimated that various forms of shifting agriculture occurred on about 30% of the world's land, while Dove (1985) stated that about half of the tropical land was affected. In summary, shifting cultivation has been a widespread traditional practice across a variety of landscapes and regions, affecting hundreds of millions of people globally

The Shillong Declaration (2004) recognised that shifting cultivation was a way of life for large numbers of indigenous, tribal, and other poor and marginalised highland communities and that traditional shifting farming systems were being strained by external and internal forces. Satapathy and Sarma (2003) believed that jhum was a predatory agricultural system characterized by indiscriminate deforestation and burning of forests, inefficient land use, resource degradation, ecological imbalance and negative socio-economic consequences.

Warner (1991) lamented that jhum growers were blamed for deforestation in tropical regions, adding that the blame was actually wrong. She argued that jhum cultivation does not involve the destruction of the forest, but the restoration of the forest. She further added that it is a complex agricultural system that is neither primitive nor destructive.

In an interview with Down To Earth, Ramakrishnan (1993) described shifting agriculture as a scientific strategy that aims to exploit the soil fertility promoted by forest growth and release it through the slash-and-burn technique. This practice resulted in rapid nutrient leaching, largely because of the steep topography and abundant rainfall in the area. As a result, farmers have adopted a diverse cropping schedule, often growing between 30 and 35 crop varieties to optimise nutrient utilisation. This diversified farming system effectively met their protein, grain, and fibre requirements. Shifting cultivation has proved to be an outstanding example of adapting production systems to specific ecological niches. Despite its superficial similarities, the northeast region comprises a variety of different systems.

Kamajou (1983) described the socioeconomic and institutional changes in shifting cultivation as a result of two phenomena - a growing population and an increased need for cash income. His description of the disadvantages of shifting cultivation includes the following:

a) Farmers' low compensation for their labour needs and supply was mainly due to the absence of markets.

b) The enormous and systematic loss of forests and forest products, as well as the deterioration of forest soils, were consequences of the shift in management.

c) Limited investments have resulted in low production due to inadequate compensation, making all investments economically undesirable.

1.5. Steps of jhum cycle

Jhum was cyclical and the cycle included a range of land use activities (FSI, 1997; Thrupp, 1997). The steps or practices of jhum cultivation vary depending on the country, climate, geographical conditions, distance of labour, and type of crop (Lalengzama, 2016). The jhum cycle is influenced by population pressure, forest characteristics, terrain, slope angle, soil texture, and rainfall. Lower population density areas have longer jhum cycles (15-25 years), whereas higher density areas have shorter cycles (5-10 years). Land selection for shifting cultivation is not predetermined and there is always room for choice. The duration of cropping and fallowing varied across regions and tribes. Originally, jhum practitioners had vast areas to move through, and the time taken to return to the same plot was unknown. However, with the current increase in population and limited space, contemporary cultivators have fewer options. Their world has become smaller, and they must contend with themselves by moving in increasingly confined circles over time (Chandel, 2017). The cycle includes the following phases in sequence: site selection, preparation and clearing, burning, planting, weeding, protecting, harvesting, and permitting (Sharma, 1976; Jain et al., 1976; Thrupp, 1997).

1.5.1. Site selection

The site selection was based on the ease of clearing vegetation and soil fertility (Siddiqui & Chohan, 2015). Other factors considered when selecting the location were accessibility and distance to the village; the size of the field depended on the size of the family (Guite, 1999). Another important aspect when choosing a location is the colour of the soil. Black or dark soil is the best choice for cultivation, as confirmed by laboratory analysis in the Amazon (Johnson, 1983; Balee, 1989). Termite mounds are also preferred for shifting cultivation in Africa because their soil water, organic matter, silt, and clay contents are higher (Mielke, 1978; Mielke & Mielke, 1982; Arshad, 1982; Nyamapfene, 1986).

Dar (1970) highlighted key factors influencing jhum site selection: (i) Adequate fallowing to restore soil fertility is crucial, (ii) rocky, erodible soils are avoided as are shaded slopes, (iii) proximity to water sources is essential, along with sufficient trees for fencing, (iv) distance from the village for accessibility is considered. By collectively evaluating these environmental and logistical criteria, the most suitable sites were identified to sustain jhum cycles, reflecting the intimate ecological knowledge of shifting cultivators.

1.5.2. Site preparation and clearing

Site clearance typically commenced between December and March after site selection. Trees, bushes, and herbs were cut and sun-dried to prepare for controlled burning before the monsoon onset. The timing and execution of burning depended on village authorities or chief and mutual agreements to prevent uncontrolled spread of fires. Farmers marked site boundaries and established fire lines as a preventive measure. Burning serves important purposes such as boosting crop yields and weed control (Rambo, 1980; Uhl, 1983).However, it also affects the physical and chemical properties of the soil (Singh & Prasad, 1976).Burning elevates pH and cation levels but decreases carbon and nitrogen levels (Ramakrishna, 1988; Kato et al., 1999;

Wapongnungsang et al., 2021).While ash acts as a natural fertiliser (Sen, 1992), burning causes volatilisation losses of nitrogen and sulphur and reduces phosphorus and potassium (Kato et al., 1999).It increases pH, nitrogen, and available phosphorus, but decreases carbon and microbial biomass in soils (Wapongnungsang et al., 2021). Hence, burning had both positive and negative effects on soils and ecology (Plate 7, 8).

1.5.3. Planting and sowing

The cultivation of grains and crop seeds begins immediately after burning (Lalengzama, 2016). Planting and sowing the seeds were mainly carried out by the women of the household, while the male members supported them by building a rest hut. The hut served as a mini-home for farmers. They were used to protect against rain, heat, and wind, and to safely store the utensils and firewood collected by the farmers (Plate 9). Before sowing the seeds, cloud formation patterns, sky colour, and rainfall dynamics were carefully observed and considered (Freeman, 1970; Schlegel, 1979). The field had a different fertilisation pattern when cultivated, and different crops were grown in different microclimates (Rappaport, 1971; Wilken, 1972; Harris, 1976) (Plate 10, 11, 12).

1.5.4. Weeding

The removal of weeds, unwanted herbs, and shrubs other than planted flora from fields is called weeding. Almost half of the plant species in the field are not planted with Amazonian crops (Alcorn, 1989). Weeds were not the only factor causing problems for the farmers. Many willow farmers tolerate crop losses caused by deer, monkeys, birds, mice, and other pests (Denevan, 1978; Poulsen, 1978).

After the field was cleared and burned, women's troops took control of the field's affairs. Therefore, sowing and weeding were primarily the work of women. Many farmers believe that if weeds are not removed, they would deplete all nutrients for the crops being grown. Weeding is a continuous process that can take at least two days to even a week depending on the size of the field. Field weeding continued until crop or vegetable maturity.

1.5.5. Harvesting

After the weeds were pulled, the farmers waited for the harvest. This was the result of all the efforts and work that the farmers devoted to their fields. During the weeding season, some vegetables are harvested in the form of leaves, stems, flowers, and fruits. However, most harvests occurred at the end of the jhum cycle. The harvested material was stored in the rest of the hut, which was built by men during burning. The harvested plants were separated and differentiated based on the parts harvested, including the fruits, leaves, stems, and roots. They can also be differentiated according to culture type. For example, rice can be stored in the drier parts of a hut, whereas other crops can be stored in open spaces. Once the harvest is complete, the crops can be transported to the farmer's home (Plates 13, 14, 15, 16, and 17).

1.5.6. Transport and fallow

The harvest was largely transported back to the village by men with contributions from women. Most transport was carried out manually or with ox carts (Plate 18). Currently, some farmers use Kabuta, a smaller version of a tractor, to transport the harvested crops.

The field can then lie fallow and regenerate after harvest, and forest regeneration is an essential activity to ensure succession (Lalengzama, 2016). Once the jhum cycle was completed, the site was naturally regenerated and could be used as a planting site again. The fallow period varies from place to place; it used to be around 20 to 30 years (Bhuyan, 2019), but now it is only around three to five years (Sati, 2020). The fallow period (intervening period between two cropping cycle), clearing of vegetation, and burning are among the most important aspects of Jhum (Thrupp, 1997).

1.6 Economic yield of jhum cultivation

Lewis (1955) viewed economic development as a mechanism for shifting factors of production from a low-productivity agricultural sector using conventional technologies to a new and more efficient manufacturing sector. A DFID paper (2004) highlighted the historically close relationship between different poverty reduction rates over the last 40 years and agricultural performance differences, particularly agricultural productivity growth. Detailed observations of farmers by Dobby (1950), Conklin (1954), Pelzer (1957) and Spencer (1966), particularly in Southeast Asia, were relevant in understanding the problems in all respects and the socio-economic circumstances of farmers. A serious socio-economic problem was also created by the short jhum period and persistently low agricultural yield in clan-controlled areas (Roy & Verma, 1976). Singh & Mate (2013) and Sati (2020) added that the socio-economic status of tribal communities mainly depends on agriculture and allied activities and that jhum is not economically viable.

The decline in jhum cycles not only resulted in low economic returns as soil ecology deteriorated but was also recognised as a sense of poverty in tribal communities with stable livelihoods (Bhuyan, 2019). Jhum was not only an ancient farming tradition, but was also inextricably linked to the culture and identity of those who practiced it (Schendel, 1992).

1.7. Scope of the study

Both Mizoram and Manipur fall under the Indo-Burma biodiversity hotspot, which means that both states have rich biodiversity of flora and fauna. However, they differ in physical and geographical features. The main occupation of the rural population is agriculture, and their livelihood and living status depends entirely on the agricultural production of their fields. Agriculture, particularly in the form of jhum, will continue to play a pivotal role in the rural population of these states.

The study aims to compare how jhum cultivation is affected by soil properties and climatic conditions. The research is also expected to help document various crops grown in jhum fields based on edapho-climatic conditions and altitudinal gradient. The management strategies formulated would sensitise farmers to managing crops based on climate and soil conditions.

1.8 Objectives

The objectives of this study are to carry out a detailed comparative study of jhum practice adopted in the Churachandpur district of Manipur state and the Champhai district of Mizoram State. Thus, the specific objectives of this study are as follows:

1. To document the crop composition in selected jhum fields along an agro-climatic gradient.
2. To compare the soil characteristics of the study sites.
3. To quantify the production of selected crops at the study sites.
4. To assess the economic viability of the selected jhum fields.
5. To recommend suitable management practices for sustainable agro-practices.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Jhum: Ancient Roots, Sustainable Future

Jhum, a prominent forest-based farming system that is ecologically and sociologically sound and in low demand, represents a tribal lifestyle deeply intertwined with their cultures, with cultivation patterns that mimic diverse natural ecosystems, shielding the soil from sunlight and rain (Srivastava, 2017). Jhum cultivation remains a complex and misunderstood form of land use, and the debate and diversity of opinions on its advantages and disadvantages are due to the allocation problem and should be readily accepted as a rational land use system (Nath et al., 2022).

Although jhum has negative effects, it helps conserve agrobiodiversity, especially rice, vegetables, and fruits (Das & Das, 2014). Jhum is much more than managing soil fertility and crop productivity; it also helps maintain balance between energy, proteins, and medicinal components, providing an important link between social reproduction and biological components and the use of fire is an important component as it promotes soil fertility, pest and weed control, and prevents the use of chemicals in the fields (Yadav, 2013).

Traditional knowledge of soil fertility management, pest prevention, soil erosion prevention, food grain and seed preservation, and environmental management are the main reasons for the sustenance of jhum and the surrounding ecosystems (Senotsu & Kinny, 2016). Despite the CO_2 emissions from slash-and-burn tillage, the fallow phase of this farming system serves as a carbon sink, and the carbon released is distinct from the gaseous emissions of chemical-based farming systems. The uniqueness of this system lies in the renewal of soil fertility during the fallow period (Ducourtieux, 2005).

The greatest threat to Southeast Asia's ecological treasure, forests, biodiversity, and natural resources is settled agriculture rather than shifting cultivation, which permanently replaces dense forests with single crops such as rubber, palm oil, coffee, bamboo, corn, cassava, and ginger (Fox, 2000). In the 1970s and the 1980s, excessive deforestation in Asia, Africa, and South America, fuelled by developed nations' demand for wood, became a global environmental crisis. This has prompted scientists to concentrate on indigenous tribes living in these woods and their changing farming methods. These communities have constructed sustainable food production cycles by combining their traditional knowledge of land classification, different crops and species, and appropriate agricultural techniques. Their social structures, land ownership patterns, customs, and farming techniques have turned over centuries to not only maximise food production, but also safeguard the sustainability of their shifting agricultural systems (Yin, 2015).

Farmers have made various efforts to protect soil nutrients from erosional loss and utilise available soil fertility on mountain slopes by preserving valuable species during slash-and-burn operations, managing a mixed cropping system in which crop biodiversity is organised along the hill slope, and using selective weed control rather than total weed control, as in modern agricultural practices, ensuring the sustainability of agricultural systems (Ramakrishnan, 2015). Jhum has several benefits, including the preservation of indigenous culture, the production of different subsistence crops, and the security of food for months. The farming method incorporates minimal tillage and minimum soil disturbance, and is based on rainfed farming without irrigation, which increases agrobiodiversity and preserves seed preservation systems. There is a market demand for cash crops cultivated through jhum farming, such as ginger, turmeric, chili, and cucumbers, which provide a source of income in hilly areas while preserving soil fertility through crop rotation and different minerals in the soil (Panda and Sarkar, 2015).

Indigenous tribal farmers possess a valuable reservoir of local knowledge, obtained through extensive practical experience and experimentation. This knowledge is essential for creating straightforward, innovative, and socially acceptable classification systems that can effectively contribute to the development of socially significant and sustainable production technologies (Sinha et al., 2020). Indigenous knowledge is intrinsically embedded in the cultural fabric of tribal societies and has demonstrated its efficacy in the stewardship of local resources.

Individuals who possess indigenous knowledge exhibit a profound bond with the natural world and showcase the responsible utilisation of scarce environmental resources, thereby actively contributing to the management of resources and safeguarding the environment. It is important to base all developmental efforts on knowledge and understanding of indigenous wisdom. This wisdom has allowed indigenous communities to coexist harmoniously with nature and engage in sustainable resource management practices for a long time (Sengupta, 2015).

Indigenous knowledge in Monochoa, Colombia encompasses practices such as agrobiodiversity management, crop rotation, fallow farming, and traditional seed preservation. These practices play a crucial role in conserving agrobiodiversity, promoting sustainable land use, and safeguarding the cultural heritage of indigenous communities (Marentes et al., 2021). The Murut community in Sabah, Borneo, possesses indigenous knowledge that encompasses careful selection of tropical plants, practice of shifting cultivation, and implementation of traditional land management techniques. This knowledge plays a crucial role in the conservation of biodiversity, promotion of sustainable land use, and the preservation of cultural heritage sites. However, challenges such as deforestation, land tenure issues, and the need to adapt to climate change continue to Traditional Ecological Knowledge (TEK) plays a vital role in the evolving agriculture and forestry practices in East Borneo. It combines extensive knowledge of the forest with a focus on sustainable resource utilisation and cultural preservation. TEK contributes to making informed decisions about land use, promoting sustainable agriculture, enhancing community resilience, facilitating responsible resource management, and supporting biodiversity and conservation initiatives (Siahaya et al., 2016).

The Dayak Ngaju community in Central Kalimantan relies heavily on local knowledge to shape and enhance the shifting agricultural practices. This information is deeply rooted in cultural traditions, and serves to maintain a group's identity and cohesiveness (Nopembereni et al., 2019). Local wisdom is transmitted intergenerationally to safeguard ancestral knowledge and to provide flexibility in response to changing circumstances (Nopembereni et al., 2019). The agricultural knowledge and practices of the indigenous Moron people in Bombana District, Southwest Sulawesi, highlight their expertise in shifting cultivation, crop diversification, sustainable land management, and local seed systems, emphasising the cultural significance of agriculture within the Moronene community and the crucial connection between indigenous, traditional, and ecological knowledge (Limba et al., 2016).These practices contribute to sustainability, cultural preservation, and community resilience, specifically in areas of holistic land management and indigenous well-being (Limba et al., 2016).

Farmers in the Eastern Himalayan region have acquired technical knowledge and skills through experience and practical learning, integrating ecological management with modern scientific agricultural practices and indigenous traditional knowledge to develop improved agriculturally suitable technologies. The Himalayan economy is centred on the sustainable integration of land, water, and agricultural systems (Mukherjee, 2012). Indigenous and traditional knowledge is vital to the effectiveness of shifting cultivation methods such as crop selection, soil management, crop rotation, and conservation activities, contributing to sustaining biodiversity, carbon sequestration, and local food security (Bhagawati et al., 2015). Incorporating indigenous and traditional knowledge into shifting cultivation systems represents a valuable resource for sustainable agriculture and ecosystem management, with the potential to increase food security, protect biodiversity, and mitigate climate change. However, challenges, such as deforestation and limited market access, must be addressed if these traditional farming methods survive (Bhagawati et al., 2015; Dasgupta et al., 2021).

Indigenous agricultural practices in northeast India, such as Panikheti in hilly terrain, Apatani method of rice cultivation on the Apatani Plateau, Zabo agriculture, alder (*Alnus nepalensis*)-based agricultural systems, alder- and large-scale cardamom cultivation, bun cultivation method, bamboo drip irrigation method, and pond cultivation in the plain, promote sustainable agriculture by using locally available resources (Das et al., 2012). Traditional agriculture has proven its efficacy, flexibility, and resilience in ensuring sustainable food production under changing climatic conditions. The bun farming practices of the Khasi and Jaintia tribes of Meghalaya rely on the efficient use of limited biomass and land resources, organic fertilisers and pesticides, and a total dependence on rainfall conditions, contributing to the sustainability of the system. Farmers traditionally leave land fallow for a period of one to three years to restore soil fertility; however, due to factors such as population growth, increasing food demand, limited land availability, and changing socioeconomic conditions of farmers, traditional bun cultivation has undergone various modifications, including changes in cropping patterns, crop selection, pest control strategies, and adjustments to the fallow period (Upadhaya et al., 2019).

Indigenous and local knowledge and practices (ILKPs) associated with jhum in the communities of Nagaland include aspects such as seed selection for beans and Nagaland rice, use of ash, cow dung, and chicken dung as fertilisers, intercropping, crop rotation, soil conservation methods, use of natural pesticides, traditional agricultural implements and transportation methods, promoting livestock farming for economic purposes, cultivation of multi-purpose crops and trees, forest conservation, reforestation strategies, traditional water conservation techniques, knowledge related to disaster risk reduction, and livestock and health care practices. Indigenous and traditional knowledge has had a tremendous influence on modifying agricultural techniques, notably in Nagaland (Dasgupta et al., 2021).

Indigenous traditional agricultural practices in Manipur, India, include various techniques such as the use of nurseries for seedlings in dry conditions, protection of maize from parakeets, use of Chinese mustard as a companion plant for pest control in Cole crops, use of Artemisia parviflora for pest control, deterring birds from crops by panels hanging from bamboo poles, using bamboo mats for grazing, planting bamboo near Parkia plants to prevent disease and pests, burning dried leaves of *Goniothalamus sesquipedalis* and *Plectranthus ternifolius* to repel pests in stored grains, use of *Clerodendrum serratum* to control pests in paddy fields, raising ducks in paddy fields for pest control, use of Nishinda branches to protect rice hispa in paddy fields, control of gundi beetles in paddy fields, use of ash to protect against powdery mildew and other pests, control of rat infestation in jhum areas, and two practices to maintain plant diversity (Ansari et al., 2021). The Mao tribe, an indigenous group, demonstrates a remarkable integration of traditional ecological knowledge with their jhum farming practices. This integration allows them to adapt to changing agricultural conditions, while maintaining sustainability. Their approach encompasses the use of organic fertilisers, traditional insect management techniques, and ecological weed control methods, all of which aim to enhance the soil quality and crop productivity. The tribe developed a sophisticated crop rotation system that carefully selects plants based on pest resistance and soil fertility requirements. This system effectively preserved their time-honoured agricultural methods, showcasing the tribe's ability to sustain farming practices across generations while adapting to modern challenges (Pfoze et al., 2010).

The Mara people of Mizoram, northeast India, employ numerous indigenous technologies and climate change adaptation strategies that are strongly entrenched in the community's awareness of their environment and are suited to their individual requirements. These practices include the use of natural fertilisers, particularly cow dung and livestock waste, to improve soil fertility while reducing reliance on chemical fertilisers; the use of bamboo as a site indicator for agriculture because it preserves soil, provides shade, and maintains soil moisture; the use of ash from burned vegetation to improve soil fertility and repel insects and pathogens; selective felling of trees in community forests to contribute to sustainable forest management and minimise land degradation; the use of traditional tools and equipment such as 'chem' and hoe in various agricultural activities; and the influence of indigenous spiritual beliefs on land use decisions, with sacred sites and specific objects influencing agricultural decisions. These traditional methods underscore the relevance of local knowledge for climate change adaptation and sustainable resource management to enable the Mara people to flourish in their changing environment (Sahoo et al., 2018).

2.2. Jhum cultivation - Global Scenario

Jhum cultivation was predominantly concentrated in the tropical parts of the world, and Chomitz et al., (2007) estimated that roughly 70 million people resided in tropical regions. A huge number of people in Southeast Asia depends on jhum for their livelihood and nutrition. However, the actual numbers are unclear and are believed to be between 14 million and 34 million (Mertz et al., 2009). In the 1980s, between 300 and 500 million people worked as shifting farmers, and in Asia, over 400 million people relied on forests, many of which were involved in shifting agriculture (IFAD, IDRC, CIIFAD, ICRAF, & IIRR, 2001). Jhum remains prevalent in diverse tropical and subtropical locations, notably in the humid tropics of West and Central Africa, Southeast Asia, and South and Central America (Lal, 2005). The Adivasis in central and southern India, the indigenous people of eastern Nepal and northeast India, as well as in the Chittagong Hill Tract and on the borders of Myanmar participated in the conversion of agriculture (Erni, 2015).The Shillong Declaration (2004) noted that the cultivation of jhum crops is vital to production systems in both agriculture and forestry to assist many ethnic and tribal communities in the tropical and subtropical highlands of Asia and Africa in supporting and securing livelihoods in Latin America. The majority of individuals belonging to ethnic groups in the categories of ethnic minorities, tribes, hill tribes, and aborigines or indigenous peoples have actively relocated across South and Southeast Asia (Erni, 2015).

Smith (2005) posited that in western Panama, jhum cultivation significantly influenced the relationship between indigenous people and wildlife, with families in the Rio Caloveborita region depending on it for animal husbandry, hunting, fishing, gathering wild food, maintaining two to three active gardens per household, and allowing cleared vegetation on new farms to decay because of the absence of a distinct dry season. In the Dayak village of Kemera, West Kalimantan, Indonesia, fallow farming, primarily rice farming, has been practiced for over 200 years, involving the removal and incineration of vegetation from approximately one hectare of primary or secondary forests devoid of standing trees (Lawrence, 2005).

Gafur et al. (2003) referred to jhum as a traditional agricultural practice of the indigenous people of the southeastern hills of Bangladesh, known as the Chittagong Hill Tract (CHT). The results of their study showed that the overall impacts of enhanced jhum in the CHT were detrimental both on-site and off-site, including loss of upland soil fertility and increased downstream flooding, erosion, and sedimentation. Khisa & Mohiuddin (2015) attributed the increased pressure on the limited land of CHT to government initiatives such as the settlement program, the

Kaptai Dam construction, monoculture afforestation programs, and the enlargement of forest reserves on community-owned land, which resulted in farmers shortening the jhum cycle and intensifying cultivation. They highlighted the reasons for jhum's continuous use in CHT: it has been a generational practice strongly rooted in their culture and customs, jhum fields were their primary source of food and vegetables; and there were rare off-farm earning options in distant places.

Oba et al. (2002) found that traditional sorghum cultivation in the lower floodplain of the Tukwel River in Kenya, characterised by agricultural landscapes of varying ages, a strong connection with forest landscapes for livestock grazing, and the practice of retaining old trees while removing young ones, not only established sorghum gardens along the river channel but also promoted forest regeneration and ecosystem diversity by creating highly diverse and heterogeneous vegetation in the floodplain.

Eastmond & Faust (2006) highlighted that the Maya of Mexico's traditional Milpa agriculture, which involved cultivating main crops like corn, beans, squash, chilies, and root crops for thousands of years, alternated between 2-3 years of cultivation and 7-30 years of fallow period, but due to population pressure, the fallow periods reduced drastically to only 5-6 years, insufficient for complete forest and soil fertility restoration. Parson et al. (2009) asserted that the Milpa agricultural system, a practice involving clearing, burning, and crop cultivation in the Yucatan Peninsula for over three millennia, experienced a production collapse due to the decrease and shortening of fallow periods, with their study concluding that the major causes of Milpa yield loss were increased weed pressure and reduced fertility.

Brunn et al. (2005) examined the relationship between fallow length, soil nutrients and upland rice production in Sarawak, Malaysia, and concluded that fallow period was directly proportional to rice yields and that nitrogen and phosphorus availability increased due to the shorter period decreased significantly and lay fallow. However, Mertz et al. (2008) countered Brunn et al. (2005) with data from Malaysia and Indonesia, demonstrating that the fallow period was a weak predictor of crop yields, whereas fertiliser use might boost output. They felt that, alongside fallowness, other variables, such as floods, drought, and pests, also had an essential influence on determining output.

Vieira & Proctor (2007) highlighted the drastic deforestation in the Bragantia region of the eastern Amazon, Brazil, where 90% of primary forests have been lost due to shifting cultivation and slash-and-burn agriculture. In contrast, Mertz (2009) noted that despite such rapid changes in many tropical areas, jhum cultivation continues to be a vital land use system for numerous farmers in the forest-agricultural borderlands of Southeast Asia. Dalle & de Blois (2006) pointed out that although declining crop yields are a significant issue associated with reduced fallow cycles, as seen in Quintana Roo, Mexico, the availability of pasture and firewood can also be adversely affected.

Do et al. (2010) reported that in northwest Vietnam, despite the intensity of jhum cultivation, fallow stands accumulated biomass comparably to less intensive stands, albeit with delayed species richness recovery, and that secondary forest succession post-cultivation was influenced not only by the disturbance level of the cultivation period but also by factors such as the surrounding old-growth forest tree species composition and climatic conditions.

Kafle (2011) studies revealed that the Chepang of Nepal, primarily relied on jhum as their agricultural practice, and are entirely dependent on rainfall for their agriculture, and they are the most impacted in terms of health and resources due to the effects of climate change and land use transition.

Li et al. (2014) research on jhum cultivation in Southeast Asia (SEA) concluded that, due to its close ties to cultural identity and fire, jhum agriculture is a more accurate representation of the region's traditional farming methods. Despite being in transition, jhum is expected to persist in numerous rural highland areas of SEA throughout the century, with the scientific community and governmental decision-making bodies still facing constraints owing to data scarcity.

Research by Blanco et al. (2013) revealed that Vanuatu's agriculture-dominated economy, in which 98% of the rural population runs small-scale family farms with three components—perennial cultivation, shifting cultivation, and a forest and tree cultivation system—benefits greatly from jhum cultivation, which is distinguished by high biodiversity in species and crop diversity. A study by Junqueira et al. (2016) in central Amazonia showed that farmers adjusted their migratory culture and crop choice according to soil fertility; higher soil fertility resulted in higher agricultural productivity, shorter periods of fallow, increased cultivation, fewer cycles, and higher labour requirements.

In Tanzania, shifting cultivation, officially known as "*Kilimo cha kuhamahama*" and colloquially as Mahame or Malale, involves a cycle of clearing fallow forest vegetation, piling and burning it, farming, fallowing, and relocating to a new fallow area, with the cropping pattern, crops, and fallow period varying by location; maize and sorghum are the most common crops (Kilawe et al., 2018). Heinemann et al. (2013) conducted studies that revealed shifting cultivation in Northern Laos to be a practice largely dependent on by marginalized communities in remote areas, characterized by high poverty rates of 46.5% and prevalent among ethnic minorities, with an estimated 550,000 people relying on it. According to Ickowitz (2011), in southern Cameroon, the main causes behind a shorter fallow season were population pressure and market involvement, and the research found that there was no convincing evidence to imply that reduced fallowing may lead to harmful impacts.

Tran et al. (2017) highlighted that in Vietnam, which covers three quarters of the mountainous area, traditional shifting agriculture practiced by about 50 culturally distinct ethnic groups has historically ensured self-sufficiency and subsistence, but faced challenges of poor agricultural production due to short fallow periods that limited cultivation to two crops and hindered soil restoration for plant growth.

Kerkhoff & Sharma (2006) found that the Eastern Himalayan system benefited from shifting management, where farmers' innovations and shifting cultivation maintained agricultural and forestry efficiency while also enhancing forest cover and biodiversity protection. Additionally, strong local institutions established by evolving agrarian groups have supported social security and cultural integrity.

Ironside (2015) investigated the changes brought about by the intensification of cash crops and pressure on fallow land in Ratanakiri Province, Cambodia, and emphasised the critical role that women play in protecting land for future generations, guaranteeing food security through agrobiodiversity protection, product marketing, and the production and sale of cash crops.

Chena farming is a traditional technique in Sri Lanka that involves alternating forests and crops to create agricultural products, meet socioeconomic, cultural, and environmental demands, and make use of scarce resources in distant locations for everyday needs (Gunasena & Pushpakumara, 2015). They also concluded that this system was neither sustainable nor economical, calling for quick fixes such as agroforestry to boost livelihoods and production without destroying natural resources.

Borrego & Skutsch's (2019) research findings defied the conventional views of shifting agriculture, revealing that it was an inclusive practice in every community in Western Mexico, engaging individuals across the economic spectrum from rich to poor.

Li et al. (2014) observed that while agriculture remains widespread in the mountainous regions of Southeast Asia, economic integration and improved infrastructure since 1992 have shifted practices from traditional pastoralism to market-oriented agriculture, particularly impacting highland regions. However, despite recent studies showing positive impacts on local livelihoods and biodiversity, the conversion of forests into monoculture plantations raises concerns about the sustainability of potential livelihoods and environmental benefits.

Heinimann et al. (2017) estimated that shifting cultivation, including cultivated fields and fallows, covered approximately 280 million hectares worldwide, but predicted a significant decline over the next few decades, expecting it to cease entirely by 2090. They specifically projected that shifting cultivation in India and Bangladesh would disappear by 2030 and that a large portion of it in Southeast Asia would also vanish in the same year.

2.3. Jhum cultivation in India

Archaeological evidence from the Neolithic period suggests that in southern India, crop cultivation, potentially the prevailing economic system, likely preceded the formation of permanent settlements and extended across both the Ganges Valley and the Deccan Plateau (Kingwell-Banham & Fuller, 2012). Traditional agricultural practices, particularly shifting cultivation on mountain slopes, continue in many Indian states, notably in hilly regions such as the northeastern states, Orissa, and Andhra Pradesh, with the Eastern Ghats in Odisha having the most extensive area under this practice (Panda & Sarkar, 2015). Mishra (2022) made a strong case in his study that jhum cultivation is a sign of poverty and a lack of technical expertise rather than just a traditional agricultural technique. Because jhum land is unique in that it can be classified as state forests, wasteland, or abandoned land when not in use, but can also be classified as agricultural land during cultivation and forest land during fallow periods, he stressed the urgent need for a comprehensive classification system for jhum land. The same piece of land is subject to many rules and management techniques at different times owing to this cyclical shift in classification, which makes administrative and conservation activities more difficult.

Over the past century, Indian government policies and initiatives aimed at transforming cultivation practices have evolved from a focus on ending, regulating, or improving jhum cultivation and preventing agricultural relocation and farmer abandonment during the British colonial era to a more recent emphasis over the past six decades on controlling or enhancing agricultural changes through the promotion of technological advancements and development (Teegalapalli & Datta, 2017).

The Shillong Declaration (2004), a significant gathering held in Shillong, Meghalaya, brought together various stakeholders including sectors, authorities, and farmers to discuss concerns regarding shifting cultivation. The declaration emphasised the need to recognise shifting cultivation as a science-based and ecologically sustainable strategy for agricultural and adaptive forest management. It called for a supportive environment to address livelihood challenges and environmental issues, owing to rapid developmental changes and market pressures. The declaration stressed the importance of farmer participation in decision-making and policy processes, and the need for research and extension services to respond to the challenges of changing crops and mobile farmers. This highlights the importance of integrating traditional ecological knowledge into future initiatives and protecting traditional institutions and intellectual resources. It also advocated creating interactive forums at all levels for information exchange and recognised the crucial role of women in crop transitions, calling for development measures to address this factor.

The tribal-dominated areas of Odisha have traditionally depended on jhum cultivation and tree-felling for firewood and timber, leading to extensive deforestation and ecological imbalances over several decades. The Orissa Tribal Development Project, funded by the International Fund for Agricultural Development (IFAD), has been discussed for its positive impact on creating long-term economic viability, empowering tribal populations, and revitalising the devastated ecosystem of the project area (Satapathy & Sarma, 2003).

In response to the economic backwardness and low yields resulting from the ancient practice of jhum, or slash-and-burn agriculture, which supports the livelihood of a million tribal people in Odisha, the government launched the "Colonization Program" in the 1960s to promote settled agriculture. However, it often led tribal residents to become labourers instead of landowners, prompting the state government to implement a watershed-focused strategy for judicious land use through the Soil Conservation Department (Government of Odisha, 2006).

Dhanaraju (2014) elucidated the Podu farming systems of the Andhra Agency prior to independence. Tribes like the Jatapus, Konda Reddis, Savaras, Porjas, Konda Doras, and Khonds were heavily dependent on podu cultivation, and despite rapid changes in political scenarios, lifestyle, and tribal behaviour, their agricultural practices and natural exploitation remained constant. Podu agriculture was primarily used as a means of survival rather than a means of making a profit, but it was crucial to the tribal economy for guaranteeing year-round food availability.

Kumari (2016) stated that jhum, which is also referred to as "Podu”, "Vegad”, and "Padaka”, is found in several Andhra Pradesh districts. The jhum of Srikakulam occupies 7.4% of the district's total forest area and provides livelihoods for 1.34 lakh isolated tribal people. Among Andhra Pradesh's tribal districts, Visakhapatnam and East Godavari have the highest rates of jhum farming (Satapathy & Sarma, 2003). The socioeconomic standing of East Godavari farmers is affected by government rehabilitation programs. Owing to their nutritional preferences for fast-growing millet crops and environmental concerns, tribal people are still not persuaded to abandon agriculture.

The Green Revolution, initiated in the 1960s, brought about a significant transformation in India's agricultural landscape, leading to enhanced food security and crop quality. This has been achieved through the introduction of high-yielding crop varieties and innovative agricultural practices, such as the use of fertilisers and irrigation, resulting in self-sufficient agriculture, a substantial supply of grains, and remarkable agricultural growth (Larson et al., 2004; Meena et al., 2013; Chand & Singh, 2023). Over the past 17 years, the agricultural sector in India has witnessed an unprecedented growth rate of 3.38 percent, underscoring the profound impact of the Green Revolution on Indian agriculture (Chand & Singh, 2023).The country saw a dramatic increase in grain production, from 74 million tons in the 1960s to 134 million tons in the 1990s.This substantial increase in production played a pivotal role in improving food security and facilitating intermittent food exports during the 1980s and the 1990s (Larson et al., 2004).

Although the Green Revolution significantly improved India’s agricultural output and food security, it also had a negative impact. Nelson et al. (2019) noted that the focus on subsidized high-yield crops led to a decline in local crops like indigenous rice and millets, causing their extinction. Meena et al. (2013) pointed out environmental issues such as pollution from excessive pesticide use, impacting human health and ecosystems. Reliance on synthetic fertilisers results in reduced soil fertility. The emphasis on high-yield crops has also caused a loss of agricultural diversity and resource disparity, thereby disadvantaging resource-limited farmers.

Jhum cultivation has been a traditional practice in India for generations and requires a shift in cultivation techniques. Although it is an essential part of the livelihoods of many tribal communities, there is concern about its impact on the environment. With increasing population and land degradation, there is a need for more sustainable and scientific approaches to agriculture in these regions. The government and other organisations are taking steps to promote alternative farming methods and support farmers in transitioning from jhum cultivation. Finding a balance between preserving cultural practices and addressing environmental challenges is critical to benefiting both farmers and ecosystems in the long term. Continuous research and collaboration are needed to find viable solutions to ensure food security, while conserving natural resources in these areas. Overall, jhum cultivation remains an important aspect of Indian agriculture; however, efforts must be made to create more sustainable practices for the benefit of all stakeholders.

2.4. Jhum cultivation in Northeast India

It is well known that jhum is a major source of income in Northeast India (Patiram et al., 2003; Panda & Sarkar, 2015; Srivastava, 2017; Bhuyan, 2019; Pandey et al., 2020). Its contribution in maintaining food security has also been acknowledged (Verma et al., 2017; Bhuyan, 2019). Furthermore, according to Panda and Sarkar (2015), Srivastava (2017) Swami (2018), Pandey et al., (2020), and Michael (2022), it is inextricably linked to the customs and culture of the area. According to Das & Das (2014), this practice had pre-colonial roots, and some authors even speculate that it may have ancient roots.

Ramakrishnan (1992) described northeast India as home to over hundred tribal communities that were highly isolated due to language, topography, and sociocultural factors. Subsequently, there were over a hundred variations of jhum practices, which also constituted the primary land use in the region. Paul et al. (2017) described that more than 70% of the region was mountainous and 65.59% of the area was covered by various forest types, resulting in hilly topography, lush forests, diverse biodiversity, ethnic diversity, remoteness and marginality. Panda et al. (2017) estimated that the total jhum cultivation area in northeastern India was 0.76 million hectares, which was 80% of the total jhum cultivation area in India (0.94 million hectares), whereas Deka & Sarmah (2010) observed that in the northeast hill region of India about 2.7 million hectares, i.e., 14.19 percent of the entire country affected by shifting cultivation.

Assam, Meghalaya, Nagaland, Mizoram, Arunachal Pradesh, Manipur, Tripura, Bihar, Odisha, Madhya Pradesh, Andhra Pradesh and Karnataka had high jhum cultivation rate and all of them adopted the same method of cultivation and all grains and vegetables were grown as a single one plot, which was a unique feature (Pasha et al., 2020; Singh, 2024). In this region, the use of abundant natural resources of hilly terrain, particularly rich vegetation, to meet food needs through the traditional jhum farming method has led to the exploitation of flora and fauna, highlighting the importance of conservation efforts to promote sustainable agricultural production (Patiram et al., 2003).

Panda et al. (2017) noted that the prevalence of jhum cultivation, which is mostly found in hilly and forested areas, is influenced by a number of factors, including land constraints, demographic pressures, farmers' low levels of education, and political planning that occurs without local input. They also noted that the transition from jhum cultivation to more profitable alternatives such as horticulture and crop cultivation is hampered by limited access to markets, tools, and knowledge.

Many variables contribute to the resilience of jhum in hilly areas, according to NITI Aayog's (2018) evaluation; Food insecurity has been inadvertently caused by government initiatives to promote crop diversity and stationary agriculture; additionally, many farmers continue jhum as a means of defending their rights and preventing the loss of their property; jhum is seen as more than just a means of producing food; farmers also derive numerous benefits from it; Jhum cultivation is still widely practiced in locations that are either untouched by programmes or when programmes only have a limited effect on particular areas or populations; Lastly, the need for financial resources is what hinders the transition to modern agriculture, compelling encouraging farmers to continue growing jhum, as it doesn't require loans or financial investment for production.

Swami (2018) posited that indigenous communities in Northeast India demonstrated a profound affinity for the jhum cultivation method, which can be traced back to their ingrained customs and beliefs in this traditional technique, in addition to their nomadic inclinations. Despite the region's numerous constraints, including physical, institutional, and socioeconomic barriers, these communities continue to practice low-input, low-yield agriculture.

In their exhaustive research, Pandey et al. (2020) scrutinized the intricate relationship between indigenous communities and jhum cultivation across six states in Northeast India, encompassing 59 villages; their findings revealed that jhum was profoundly ingrained in the culture and lifestyle of these communities; they discerned three forms of attachment—natural, social, and economic—that bolstered the continued practice of jhum cultivation; the study underscored the innovative adaptation of indigenous jhumias to exploit natural resources while adhering to cultural norms, thereby ensuring sustainability and fortifying their bond with the land; notwithstanding governmental discouragement, jhum exhibited tenacity and resilience in confronting challenges such as natural disasters and health crises; the research accentuated the necessity to acknowledge and conserve shifting cultivation as a crucial component of sustainable development in Northeast India, considering its cultural relevance and contributions to biodiversity and essential resources.

According to Deka & Sarmah (2010), jhum involves the use of multiple crops in a single field by tribal farmers, thereby reducing the need for extensive fertilisation and irrigation and simplifying soil preparation through controlled burning or shredding of weeds and under brushes. However, the practice is not without environmental consequences, and tribal communities are drawn to it because of its cultural significance and ease of use despite its simplicity.

Goswami et al. (2012) conducted a thorough investigation into the factors that influence farmers in Northeast India to adopt slash-and-burn agriculture and carefully examined a variety of personal, social, economic, institutional, and physical factors, including the respondents' age, primary occupation, annual per capita income, the area currently under cultivation, the practices of slash and burn agriculture that are currently in place locally, farmers' perceptions, and their ability to access credit. All these factors were found to have statistically significant effects on the adoption of slash-and-burn agriculture. Factors such as the accessibility of land resources and the slope of land were instrumental in the adoption of this agricultural practice, underscoring the imperative for the proactive engagement of government agencies, non-governmental organisations (NGOs), and self-help groups in the region to mitigate the practice of slash-and-burn agriculture by extending institutional support to farmers.

The average jhum plot is 1–2.5 ha in size and is managed by a family of two adults and three to four children (Ramakrishnan, 1992). The jhum cycle has shortened significantly from over 20 years to just 4-5 years (Ramakrishnan, 1992; Panda et al., 2017), while Nath et al. (2016) as 3-5 years. Swami (2018), on the other hand, highlighted the major problems of jhum cultivation in northeast India, which include acidic soils, high rainfall, humidity, lower temperatures, uneven terrain, steep slopes and elevation differences, all of which affect crop production.

In contrast, Chatterjee (2021) called for an urgent need to rethink and revise land-use classification policies and strengthen traditional agricultural and natural resource management practices to ensure inclusive and sustainable rural development while mitigating the impacts of climate change.

According to Michael (2022), traditional jhum farming systems have the ability to create both a sustainable society and a healthy environment as native seed varieties are more resilient to environmental changes compared to hybrid introductions, emphasising the need to seek viable alternatives to jhum cultivation.

Chatterjee (2021) scrutinised the land use policy for jhum cultivation in Northeast India - despite jhum being a crucial economic and agricultural practice, it has been criticised by both central and state governments for its perceived threats to biodiversity, climate change, and inefficiency. The Mizoram government's New Land Use Policy (NLUP), aimed at reducing jhum cultivation and expanding forest cover, was deemed unsuccessful because of a decline in forest cover and a shift towards permanent farming. The 1998 National Forest Policy, which labels jhum cultivation as 'forest land' and its fallow period as 'waste land', discourages jhum practices without providing alternative income sources outside of agriculture. The policy's land-use classification also overlooks the different phases of jhum cultivation, particularly the fallow period.

In the past decade, Arunachal Pradesh has reduced jhum cultivation from 110,000 to 84,000 ha to mitigate environmental damage and promote conventional farming, despite the cultural significance and economic support provided to rural livelihoods and regional economies, particularly in 16 climate-sensitive northeastern districts (Panda & Sarkar, 2015).

In Tripura, land tenure and ownership structures significantly influence jhum cultivation, with the region's hilly terrain and isolation necessitating reliance on jhum as a primary food source due to scarce alternatives (Das & Das, 2014). Government initiatives to transition from traditional jhum to enhanced hill land rice cultivation have not deterred over 25,000 indigenous tribal people from continuing jhum cultivation, leading to considerable biodiversity loss and socioeconomic disparities. The Reang tribe's struggle to adapt to government-provided alternatives underscores the need to reinstate customary forest and land rights to maintain jhum agriculture (Panda & Sarkar, 2015). A study by Datta et al. (2014) on the livelihood of tribals practicing jhum cultivation in Tripura's Gomati district revealed that 39.3% of farmers had low incomes, while only 24.3% enjoyed high living standards. Factors such as educational level, family size, jhum area, annual income, fallow period of land, livestock, and material possessions were found to influence the living standards.

In Dzongu, Sikkim, shifting cultivation is a labour-intensive practice that involves all members of the family, according to Khaling & Lepcha (2022). Men handle tasks such as clearing land and felling trees, whereas women are responsible for selecting seeds, sowing them, and harvesting the main crops, including rice, millet, buckwheat, corn, sorghum, yams, taro, and tapioca. Political factors, British colonial influence, and the influx of migrants shifted to this cultivation method in the 19^{th} century. Government policies prohibiting shifting cultivation, market access, infrastructure development, a shift to cash crops such as cardamom, tangerines, and ginger, improved farming techniques, and youth migration resulting in labour shortages were the main drivers of these changes.

The main agricultural technique in Nagaland, a state in northeastern India noted for its climate and rugged terrain, was shifting cultivation. It is now more difficult to strike a balance between land usage, production adaptation to a growing population, and ecological preservation because of recent decreases in this practice, which have reduced crop yields and caused food shortages among once self-sufficient households (Panda & Sarkar, 2015). Jamir (2015) observed that in

Nagaland's Mokokchung district, jhum cultivation—a common land use system—is rapidly changing.

In Meghalaya, shifting cultivation has long been a dominant practice, resulting in a landscape characterised by both forested and jhum fields, resulting in disrupted forest connectivity, fragmented wildlife populations and increasing human-wildlife conflict, particularly in the Garo region Hills (Panda & Sarkar, 2015). The detrimental effects of slash-and-burn agriculture, a traditional practice common among indigenous communities in rural India, on the forest ecosystem in Meghalaya’s Garo Hills were thoroughly examined by Yadav et al. (2013). Their study found that this practice disrupts the shifting cultivation system and causes land degradation, deforestation, erosion, and biodiversity fragmentation, all of which are worsened by heavy rainfall in the region and steep terrain. Their research also highlighted the need to strike a balance between indigenous livelihoods and modernisation in accordance with the principles of sustainable development and promote a comprehensive strategy that combines traditional knowledge with sustainable farming techniques.

Upadhaya et al. (2019) provide an explanation of the complex dynamics of traditional bun farming, which is a method that combines food production with tree cultivation and is deeply entwined with the dynamic ecology of the subtropical hills of Meghalaya, India. Their study highlighted the farmers' desire for long-term resilience in the farming system, which is accomplished through a methodical approach that includes minimising the amount of biomass used, applying organic fertilisers strategically, applying diluted lime ($CaCO_3$) and tobacco water for pest management in crops such as potatoes, cabbage, and cauliflower, and burning residual field vegetation with a specific goal in mind to both sterilise the soil and control pests.

In addition to highlighting the importance of jhum farming for tribal tribes' culture and ecology, Srivastva (2017) acknowledged that the practice is declining because of rising land demand and population. In light of the regional context, he suggested that sustainable policies should balance economic development, environmental preservation, and tribal ways of life. He also outlined approaches, including improving valley land farming, expanding sources of income, and implementing efficient resource management. The initiatives he suggested included skill development, technology integration, alternative livelihood promotion, rehabilitation, and guaranteeing sufficient resources. Additionally, he emphasised how local administration must respect tribal viewpoints and recognise their critical role in maintaining ecosystems, while still being in line with national and regional frameworks.

Verma et al. (2017) investigated solutions to the problems caused by shifting cultivation in Northeast India, which depletes resources and degrades the environment, and recommended enhanced farming, sericulture, beekeeping, and new crops as alternatives. They also emphasised the importance of retaining traditional ecological knowledge among migrant farmers for sustainable land use.

According to Paul et al. (2017), there is an urgent need for government support to provide alternative agricultural work opportunities to sustain livelihoods and to contribute to the restoration of wastelands, forests, and the environment. Conversely, Pandey et al. (2020) contended that the aboriginal people of Northeast India continue to cultivate jhum in spite of government efforts to discourage them because it is deeply embedded in their customs and cultural practices and because there aren't any practical substitutes.

Northeast India's long-standing custom of jhum cultivation serves as a perfect example of the complex interplay among environmental, cultural, and economic factors. Despite widespread concerns about its environmental effects, finding other forms of employment and land use strategies that preserve indigenous cultures and practices remains difficult. Achieving sustainable development in this area requires a balanced approach between conservation efforts and the needs of the native populations for survival. Maintaining this balance as well as the purity of the environment is essential for preserving the socioeconomic health of these communities.

2.4.1. Jhum cultivation in Manipur

The livelihood and state economy in Manipur rely heavily on agriculture (Feroze et al., 2014; Sharma, 2019) and are heavily influenced by rainfall (Seitinthang, 2012; Roy et al., 2018).

Roy et al (2018) highlighted the complex agricultural landscape of Manipur, characterised by challenging topography, varying elevations, communal landholding, and conventional techniques with limited use of agrochemicals. This results in poor crop yields owing to a variety of factors, including heavy rainfall, soil acidity, and pollutants, mostly in hilly regions with ferruginous soils and erosive alluvial valleys.

Both Seitinthang (2013) and Feroze et al. (2014) emphasised the importance of agriculture in the Manipur economy. Feroze et al. (2014) estimated that 52.19% of the workforce in the state makes their living from agriculture, which helped to quantify its relevance. Meanwhile, Seitinthang (2013) emphasised how shaky this reliance is, pointing out that a significant portion of the labour force is impacted by the agricultural sector's heavy reliance on erratic rainfall patterns.

According to Sahoo et al. (2020), jhum farming is a traditional farming method common in Manipur, characterised by a cycle of tillage, slash-and-burn agriculture, and eventual abandonment after a few years of cultivation. Their research highlighted how widespread it is among tribal farmers in northeastern India, particularly in Manipur, who are economically disadvantaged mainly because of their restricted access to modern agricultural inputs and technology as well as their socioeconomic status. They also stressed that jhum farming contributes significantly to soil deterioration in the area because the soils in farmed regions are usually acidic and nutrient-deficient, mostly because of the rapid nitrogen depletion caused by forest fires.

The tribal economy of Manipur operated primarily as an agricultural economy, with land serving as the main means of production and livelihood. The prevalent method of cultivation in the region was shifting or jhum cultivation, with 36.44% of the population in the hill districts practising it (Singh, 2007; Reimeingam, 2017b). Among the total scheduled tribe rural population of Manipur, jhumias contributed 36.46%, highlighting the significant dependence on jhum for livelihood

(Government of Manipur, 2015; Singh et al., 2017). According to Roy et al. (2018), approximately 80% of Manipur's population relied on agriculture for their livelihood, with cultivators and agricultural labourers accounting for 52.81%. The agriculture in this region is predominantly dependent on rainfall (Roy et al., 2018).

Guite and Sharma (2023) conducted an engrossing study that revealed the dynamic shift in the agricultural landscape of the Thadou-Kuki. They traced the villages' journey from traditional jhum rice cultivation to the colourful tapestry of cash crops and non-agricultural industries, with some even shifting their focus to the intensive cultivation of poppies and high-value crops such as sesame, ginger, and king chilli.

Reimeingam (2017a) highlighted the significant reliance of Manipur's rural population on agriculture in his perceptive study and that this dependence is difficult to maintain because there are few non-agricultural job options and the disruptive practice of shifting cultivation, or jhum, which upends traditional agricultural patterns and presents technical, financial, and irrigation challenges. To address these problems, he suggested radical institutional reforms such as providing jhum substitutes, making sure there is enough working capital available for effective input utilisation, moving from communal to private land ownership to stop jhum, promoting forest preservation, establishing a minimum five-year timeframe for changing crop cycles, ensuring food security, and placing a high priority on socio-environmental safety to promote sustainable, environmentally sound, and economically viable alternatives.

The agricultural sector in the region, which was primarily based on rain-fed monocultures, showed untapped growth potential and primarily followed subsistence-oriented practices using local crop varieties and minimal agrochemical use, particularly in hilly areas. This is despite challenges such as rugged terrain, varying altitudes, communal land ownership, and traditional farming methods (Roy et al., 2018).

Conversely, Gonmei (2013) addressed the factors that together affected Manipur's hilly regions' agricultural output and economic viability. He stated that poor road connections in many agricultural areas in Manipur limited market access, making transportation a significant issue in the region. He also emphasised that the market potential for raw resources from mountainous regions was restricted owing to low population density, low consumption rates, steep terrain, and high transportation costs to distant markets. As a result, farmers would usually sell their produce to travelling merchants directly from their fields at a lower price. In addition, he explained how the hills' agriculture was facing issues due to a lack of contemporary institutions, the continued use of traditional techniques, reduced jhum cycles, and growing rural population pressure.

The serious threat that climate change poses to Manipur agriculture has been highlighted by Feroze et al. (2014). Severe weather events, including floods, droughts, and landslides, impair production and harm important crops, such as rice. Farmers face severe financial hardships due to unpredictable rainfall, which causes droughts, crop failures, and water shortages. Warmer temperatures also increase evaporation and require more irrigation. They concluded that, in addition to worsening soil erosion and degradation, climate change also reduced agricultural yields, and the combined consequences of these factors had a major influence on Manipur agriculture, food security, the fight against poverty, and general socioeconomic development.

The Government of Manipur (2013) predicted significant effects of climate change on agriculture. These effects include decreased crop yields, shorter cropping seasons, agricultural failures due to erratic rainfall, increased pest and disease outbreaks, and delayed rice planting due to delayed monsoons and droughts. Flooding and drought during critical rice-growing seasons heighten the danger of natural disasters. The state has also suffered from the consequences of climate change, which have had an impact on animal health, temperature, rainfall patterns, agricultural growth, and pest and disease outbreaks. The government has created climate-resilient agricultural technology and income development programs through national and state programs to address these effects and improve food security (Roy et al., 2018).

Singh (2022) found that although jhum agriculture is the main source of revenue in the hill parts of Manipur, its traditional cycle has drastically decreased from to 30-40 years to just 2-3 years, and in some locations, to just one year. This dramatic change has far-reaching effects on forest biodiversity, ecological restoration, and geomorphology of the highland environment. He advocated cooperation between local people, NGOs, stakeholders, and pertinent authorities as well as the sustainable management of resources affected by jhum. His study of Manipur's agricultural landscape recognised the continued existence of traditional farming as a result of socioeconomic limitations. He also noted that the scheduled tribes of the hill regions face challenges from population growth, a lack of arable land, poverty, and a lack of technical knowledge among them, which hinders the widespread practice of jhum farming.

The Government of Manipur (2013) recognised that jhum cultivation was the primary cause of changes in the state's forest cover, and thus implemented measures to promote sustainable livelihoods and adopt climate-resilient contemporary agricultural techniques. The 'Rehabilitation of Jhumias' initiative aimed to discourage jhum growers from continuing the unsustainable practice of jhum cultivation by integrating forest management with more extensive economic development initiatives. The government's integrated approach sought to provide incentives for farmers to shift from jhum cultivation to more sustainable practices, thereby preserving state forest cover and promoting economic development.

According to Sharma’s (2019) analysis, the harsh geography of the hilly highlands, which are primarily covered in forests, and consequently limited agricultural opportunities, have made the Manipur Valley the centre of the state's economic activity. Jhum was widely accepted in the hill areas and was largely dependent on the valley for food supplies.

Jhum farming, an agricultural technique characterised by manual labour and practiced in the hilly regions of Manipur, had traditionally served as the primary means of subsistence due to the scarcity of alternative employment opportunities in the field of agriculture, as per Reimeingam's (2017b) observations. The surge in population has been accompanied by increased reliance on forest lands for farming purposes, resulting in shorter crop cycles and lower yields. The organic nature of this farming method is largely attributed to the limited utilisation of inorganic fertilisers.

Seitinthang (2012) investigated the indigenous knowledge and traditional agricultural practices of the Kukis in the Ukhrul district. His study emphasised the benefits of combining contemporary technology with the traditional agricultural expertise of the Kukis, which include higher output, less effort, financial rewards from cash crop diversification, effective use of local resources, and preservation of indigenous knowledge. In addition to helping farmers, this combination promotes sustainable agriculture by creating a mutually beneficial relationship between traditional and modern farming practices.

Singh & Mate (2013) investigated the socioeconomic well-being of the Churachandpur tribal community, which relies mostly on agriculture and its allied industries. To achieve the Millennium Development Goals and improve the welfare of the tribal economy, they felt that it was necessary for the government and other relevant authorities to prioritise initiatives such as improving road connectivity, promoting education, implementing population control measures, and safeguarding agricultural lands from the potential effects of large development projects, especially in Manipur's hilly districts.

A study conducted by Thong et al. (2019b) revealed a decline in jhum cultivation over a period of 19 years, with notable decreases in Ukhrul and Chandel. The current jhum areas are 67.00% (1047.36 km^2) and 70.47% (844.17 km^2), respectively. This resulted in an average annual deforestation area of 4,455 km2. The sizes of jhum plots varied between 1-2 ha in Ukhrul and 57.5 ha in Chandel. Approximately 40% of the land in both districts is currently under jhum, with approximately 20% of that land Despite population growth, jhum field sizes, total area, and number of plots generally decreased, with the exception of Kamjong and Kasom Khullen blocks in Ukhrul, where 10–14-year cycles were common and affected 69.3% of the area; in Chandel, on the other hand, 9–12-year cycles were common and affected 53.07% of the area.

The agricultural cycle decreases from 20 to 30 years to 2–5 years, caused by population expansion and changes in property laws, and has resulted in environmental problems such as soil degradation, deforestation, erosion, and wildfires, according to Singh’s (2022) study on Manipur's jhum agriculture. He added that in order to expand jhum, land clearance and slash-and-burn methods were used more often, leading to the loss of important plant species, forest biodiversity, and wood and that the decrease in biodiversity, topsoil nutrient losses, and geomorphological erosion were caused by soil erosion from underdeveloped land. He further pointed out that previously, the ecological stability and soil quality of forested hill slopes are not seriously threatened by jhum rotations occurring every 15 years or more.

Population expansion and urbanisation in Manipur's hills led to an increasing demand for arable land and deforestation, even in reserved and protected forests, according to Reimeingam's (2017a) research. Agriculture's share of government revenue declined despite reforestation efforts, forestry and logging saw modest improvement, and jhum cultivation—common in the hills—caused soil degradation because of shorter fallow periods. He suggested jhum cycles, jhum alternatives, sufficient working capital for effective input usage, and land ownership reorganisation for a minimum of five years to address these problems.

The negative consequences of jhum cultivation and uncontrolled land use on local forests and land productivity were highlighted in the Government of Manipur (2014) New Land Use Policy of Manipur: An Approach Paper. Jhum production, mostly for subsistence, resulted in decreased soil fertility, which was made worse by hill farmers switching to lucrative but environmentally hazardous crops like cannabis and poppies, as well as forest fires that destroyed ecosystems and caused deforestation and soil erosion. These modifications have led to decreased fish productivity, changed climatic patterns, increased silt in water sources, decreased soil water storage, and natural source depletion. The allocation of natural resources is also disturbed by climate change, which influences livelihoods and causes food shortages, diseases, infrastructure damage, and resource degradation.

In his analysis of the Churachandpur Khuga Dam's effects, Zou (2011) noted that the construction of the dam resulted in the relocation of over 3000 people and a major shift in agricultural practices, with the percentage of people practising jhum rising from 6% to 44.5 % previously. As a result of a significant increase in reliance on forests and forest products such as lumber, charcoal, and firewood, a significant portion of the forest (roughly 80 %) was destroyed for the extraction of timber and forest products such as firewood and charcoal. He explained that the main cause of this was the loss of wetlands and rice fields submerged in dammed water.

The production of jhum has gradually given way in the districts of Senapati and Tamenglong to horticulture, as well as other crops like oranges, lychees, pineapples, bananas, and spices like cardamom and ginger. Despite this change, the Manipur's environmental degradation problem grew, mostly as a result of excessive jhuming, which led to mudslides and landslides that impacted public health and transportation (Singh, 2022). According to Roy et al. (2018), horticulture is important because it produces a variety of fruits and vegetables including pineapples, bananas, passion fruits, Khasi mandarins, lemons, and temperate plants. However, despite its potential, the horticulture sector was sadly underutilised, especially for small and marginal farmers in hilly areas. Additionally, they emphasised the impact of animal husbandry and poultry, especially in the hills where milk, eggs, and meat are produced. To combat the destruction of forests, Singh (2022) recommended that regulations governing the production of jhum are necessary. He also proposed that sustainable techniques should either be outlawed or incorporated into customary jhum practices. He placed strong emphasis on encouraging horticulture, beekeeping, and sustainable agriculture to reduce the negative environmental effects of jhum farming. Furthermore, he suggested that jobs be created, that the villagers be given alternative means of subsistence and sources of income, that forestry cooperatives and terrace farming be established on jhum lands in order to prevent soil erosion, and that horticulture, floriculture, and sericulture be promoted while educating the native jhum farmers about them.

2.4.1. Jhum cultivation in Mizoram

Sati (2020) characterised jhum as a practice steeped in centuries of tradition, serving not only as a livelihood but also as a way of life and the main occupation in Mizoram's rural regions. The inception of jhumming was first recorded in the 18th century, coinciding with the migration of the Mizo people to what is now known as Mizo Hills (Zaitinvawra & Kanagaraj, 2008). Despite the country's introduction of numerous programs and policies aimed at discouraging jhum, Vanlalchhawna (2015) underscored that it remains the predominant land-use method and a vital source of livelihood for the majority of Mizoram's rural inhabitants. Traditionally, Mizos prepared land for burning in February, demonstrating a close association between fire and land clearance, soil enrichment, and weed, pest, and pathogen control (Grogan et al., 2012).

According to the Forest Survey of India (FSI) studies from 2017, 2019, and 2021, shifting cultivation practices and development within the forests are to blame for Mizoram's declining forest cover, which was 531 km^2 in 2017, 180.49 km^2 in 2019, and 73 km^2 in 2021. Sati (2020) highlighted that over the past three decades, there has been a significant shift in agricultural practices in the region, characterised by a decrease in the area, yield, and output of crops from shifting cultivation and a corresponding increase in those from permanent farming methods, reflecting a substantial change in the region's approach to food production and land use.

According to Singh et al. (2013), the Lushai Hills in Mizoram are a difficult and biodiverse area with poor plant yield. Sedentary farming and jhum cultivation are important traditional agricultural activities that support the local economic and cultural traditions. They argued that low productivity was caused by the lack of contemporary technology as well as elements such as restricted irrigation, monocultures, bad infrastructure, a shortage of trained labour, and a lack of research facilities.

According to Lallianthanga & Sailo (2013), the percentage of Mizoram's terrain that is made up of abandoned jhum regions and jhum cultivation is 10.31% and 5.89%, respectively. Vanlalchhawna (2015) observed that approximately 200,000 hectares of forest were cleared for shifting agriculture, providing employment to roughly 100,000 people. Because of ecological concerns, the Mizoram government has attempted to convert from shifting to settled agriculture; nevertheless, the transformation has been gradual and shifting cultivation is still common (Zaitinvawra & Kanagaraj, 2008). According to Maithani (2005), 58,000 families were involved in shifting cultivation in 2000, accounting for 54% of rural residents' primary source of income (Sati, 2019). According to the Statistical Hand

Book of Mizoram (2018), the percentage of total agricultural land under shifting cultivation decreased from 58% in 1997–1998 to 16.9% in 2016–2017.

Das (2011) highlighted the distinct farming methods and diverse ecosystems of Mizoram, which include jhum and crop rotation, involving the coexistence of mixed crops such as rice, corn, pumpkin, cotton, cucumber, yam, and other vegetables, with rice being grown as the primary crop through wet or terrace methods. Beans, cabbage, and mustard seeds were grown during the Rabi season in the same plots, in addition to the widely used animal husbandry system. In a study published in 2008, Zaitinvawra & Kanagaraj (2008) highlighted that according to the 2001 census, 57.85% of Mizoram households were engaged in cultivation, primarily in the areas of jhum (87%) and wet rice cultivation (13%). Champhai, Kolasib, and Saiha districts had a higher proportion of shifting cultivators than Aizawl, and the majority of farmers (70%) owned less than one hectare, followed by small (20%), medium (6%), and large (4 %) farmers.

Shifting cultivation was the dominant agricultural practice in Mizoram's highlands, as reported by Sati & Rinawma (2014). They added that permanent wet rice cultivation was more common in the lowlands and valleys. Although rice production accounted for only 25% of the state's total consumption, shifting cultivation covered between 18% and 28% of Mizoram's total area and 38.64% of its net sown area. Agriculture, particularly shifting cultivation, is the primary source of income for approximately 80% of the population.

In addition to pointing out that almost half of Mizoram's households were engaged in shifting agriculture, particularly in isolated towns and villages, Grogan et al. (2012) highlighted the problems presented by the region's topography, which is mostly composed of steep gradients and encompasses over 70% of the region.

As per Raman (2001), jhum, which is a practice that integrates controlled burning and rotational cultivation, is commonly utilised in the hilly regions of northeastern India, such as Mizoram. This practice serves as a significant source of income for various tribal communities, and has a profound and lasting impact on forest regeneration and depletion.

While Chawngthu & Kanagaraj (2014) identified two common cultivation methods in Mizoram villages: the traditional jhum (shifting cultivation) and semi-settled cultivation, Zothansanga & Beingachhi (2019) emphasised the socio-cultural importance of jhum cultivation, which accounts for approximately 80% of the region's primary occupation and has historically influenced the region's economy through the farming of crops such as rice, corn, cucumbers, beans, arum, ginger, mustard, sesame and cotton.

Zonunsanga et al. (2014) argued that although jhum cultivation, which is sometimes seen as a necessary evil because of its variable nature, does not result in land degradation when limited to a single plot, the need to move fields is caused by nutrient deficiencies in the soil that lower productivity, and concluded that innovative soil conservation and efficient mitigation of soil loss could promote agricultural advancement and bring about significant systemic changes.

Comparing traditional jhum farming with integrated crop-livestock farming in Mizoram, Sangpuii & Malhotra (2016) found that the former was more profitable due to higher yields and better farm employment opportunities, and they also warned against the potential negative effects of continuing jhum cultivation, such as ecological imbalance, deforestation, soil erosion, and severe environmental degradation. One major concern was the reduction of the jhum cycle's fallow period to 2-3 years, which resulted in alarming levels of land degradation in Mizoram—34.7%—far higher than the national average of 20.2%.

Leblhuber & Vanlalhruaia (2012) explained the close relationship between Mizo community's identity and traditional jhum cultivation practices. They also emphasised the chieftaincy institution's role in creating customary laws and forest-related management systems. The Mizo community’s traditional forest management practices, which include restricted access, size limits, and sacred zones, are rooted in a strong connection to land, cultural norms, beliefs, and environmental ethics.

In Thong et al. (2019a) socio-economic and household survey of 45 households in Champhai, they looked at the topography and the spatial distribution of jhum fields and determined that the majority of the region's jhum fields were between 1.0 and 2.0 hectares in size, and that socioeconomic factors—particularly education and occupation—significantly contributed to the district's declining trend of shifting cultivation.

Lalrinsangpuii et al. (2016) found that while profit efficiency tends to decrease with age, factors including farm experience, farm size, and non-farm income positively increased profit efficiency in Mizoram. Their study also suggested that providing farmers with training might help them to adopt the most productive jhum cultivation techniques.

Grogan et al. (2012) emphasised that shorter fallow times associated with shifting cultivation have resulted in unsustainable agricultural practices that have lowered agricultural output and exacerbated environmental degradation, including soil erosion, watershed siltation, and air pollution in Mizoram. Mizoram state government introduced the New Land Use Policy (NLUP) in response to the problem of unsustainable jhum cultivation. As outlined in the New Land Use Policy Manual (2009), the main objectives of NLUP were to end jhum cultivation and provide Mizoram's farmers with sustainable means of subsistence.

The New Land Use Policy (NLUP) was introduced in 1984–85 to address land degradation and promote alternative land use, but it was discontinued in 1989–90 due to its inability to impact the forest landscape or the alternative livelihoods of jhum growers, despite the centuries-old cultural significance of jhum cultivation in Mizoram, as noted by Leblhuber & Vanlalhruaia (2012).

Although shifting cultivation is a traditional farming practice among indigenous communities in Mizoram, Vanlalchhawna (2015) highlighted an impact analysis by the Department of Economics of Mizoram University that showed how the NLUP program significantly improved the livelihoods of beneficiaries in the industrial sector who were actively engaged in their chosen careers, leading to increased income and reduced reliance on daily labour and shifting cultivation. However, 43% of the recipients did not engage in their preferred businesses, and more than half failed to effectively distribute financial aid because of factors such as insufficient skills, limited workspace, a lack of trading opportunities, and expert guidance.

The state's New Land Use Policy (NLUP), as highlighted by Bose (2019), sought to replace shifting cultivation with settled farming, particularly on palm oil plantations. As palm oil plantations have detrimental effects on biodiversity, wildlife habitat destruction, excessive use of fertilisers and pesticides, land degradation, and lower carbon sequestration, these changes have raised concerns. Women frequently take on a more submissive role in the palm oil business, as this study also highlights the gender differences in this transformation. He recommended that to address these problems, palm oil producers should guarantee land tenure for families and communities, uphold traditional land-use methods, and embrace sustainability standards.

Leblhuber & Vanlalhruaia (2012) criticised Mizoram's New Land Use Policy (NLUP), claiming that it did not adequately address core problems. They contended that, although the Indian government portrayed the NLUP as a tool to improve rural living, its real goal was to impose liberal economic principles. Conflicts within the NLUP that undermined the conventional jhum farming system were revealed through fieldwork. Jhum remained a staple crop for farmers even when they turned to income crops. They worried that this shift would exacerbate tensions between local councils and the state bureaucracy, making the NLUP unsuitable for Mizoram’s complex social and political environment.

While noting that the NLUP has reduced jhum activities and increased rice production, Zothansanga & Beingachhi (2019) emphasised the need of understanding traditional jhum agriculture in its historical context, acknowledging its labour-intensive nature and low yield, and proposing the development of sustainable alternatives. They also emphasised that long-term sustainability requires beneficiary involvement, sufficient support, market accessibility, and thorough monitoring and evaluation.

According to numerous studies and publications, Chatterjee (2021) noted that Mizoram's New Land Use Policy, 2011, which aimed to shift from jhum cultivation to permanent agriculture and horticulture, has not succeeded in creating alternative sustainable livelihoods, and has instead led to the loss of forest cover and environmental degradation in the area.

In a study on the transition from shifting cultivation to settled agriculture in Mizoram, Lalengzama (2019) discovered that larger landholdings and a shift from subsistence to commercial farming were the outcomes of the shift and that there were no notable demographic or socioeconomic differences between migrant and sedentary farmers. They argued that despite the NLUP, farmers did not exhibit a discernible preference for animal husbandry; instead, monocultures predominated, commercial crops became more prevalent, and local seeds were replaced by High-Yielding Variety (HYV) seeds. However, the preference for organic fertilisers did not change.

Sati (2019) researched the impact of shifting agriculture, which is the main source of income for small farmers in Mizoram. He discovered that although many jhumias produced grains for subsistence, this was less profitable than cash crops. Consequently, he suggests switching to cash crops for a sustainable way of life and turning jhum plots into terraced fields for permanent agriculture.

2.5. Edaphic and Climatic Factors on Crop Productivity and Soil Health

The complex interactions between edaphic and climatic factors, including soil properties and dominant weather patterns, significantly impact crop productivity and soil health. These factors interact in various ways, influencing the physical, chemical, and biological processes that govern plant growth, nutrient cycling, and overall health of agricultural ecosystems. Understanding the interplay between edaphic and climatic factors is critical for developing sustainable farming practices and ensuring food security, particularly in view of the difficulties presented by climate change and increasing population density.

2.5.1. Soil Properties

The distribution of sand, silt, and clay particles in a soil sample is known as its texture, and this property is essential for determining the ability of the soil to hold onto water, its aeration qualities, and the availability of nutrients (Abdallah et al., 2018, 2021). Sandy soils have larger pore spaces, promoting better drainage and aeration but poor water and nutrient retention. In contrast, clay soils have smaller pore spaces, resulting in higher water-holding capacity but lower aeration, which can lead to waterlogging and reduced oxygen availability for plant roots (Bronick & Lal, 2005).

The arrangement of soil particles into clusters or aggregates, or the soil structure, affects root penetration, water infiltration, and soil aeration (Frene et al., 2024).This configuration of soil particles affects the physical and chemical characteristics of the soil, which in turn affects the general health and productivity of the soil (Shaheb et al., 2021).Well-structured soils with stable aggregates facilitate water movement, gas exchange, and root growth, ultimately improving crop productivity (Kallenbach et al., 2016).Conversely, poorly structured soils with compacted layers can impede root development and water infiltration, thereby negatively affecting the crop performance.

An important factor influencing the availability of vital minerals for plant uptake is the soil pH (Barrow & Hartemink, 2023). Nonetheless, the nutritional balance may be disturbed in soils with extremely high or low pH values, either highly acidic or alkaline, respectively (Hartemink & Barrow, 2023). Plant development and production may be impaired, and toxicity or nutrient deficits may result from this imbalance (Frene et al., 2024).

The presence and availability of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients are crucial for crop growth and development. Nutrient deficiencies can lead to stunted growth, reduced yield, and poor crop quality, and excessive levels of certain nutrients can be detrimental (Hawkesford et al., 2012).

Soil organic matter (SOM) plays a vital role in maintaining soil fertility, structure, and water-holding capacity (Lal, 2020). It serves as a reservoir for plant nutrients, improves soil aggregation, and enhances microbial activity, thereby contributing to the overall soil health and crop productivity (Lehmann & Kleber, 2015).

2.5.2. Climatic Factors

Temperature influences various physiological processes in plants, including germination, growth, and reproduction (Hatfield & Prueger, 2015). Both high and low extreme temperatures can adversely affect crop growth and yield, leading to reduced productivity and quality (Lobell et al., 2011).

Water availability is essential for plant growth and development, and precipitation patterns significantly affect crop productivity (Steduto et al., 2012). Insufficient rainfall or irregular rainfall distribution can lead to drought stress, whereas excessive precipitation can cause waterlogging, limiting oxygen availability to plant roots and hindering nutrient uptake (Majeed et al., 2023).

Plant transpiration rates and water balance are influenced by relative humidity and vapour pressure deficit (VPD) (Song et al., 2022). Plants frequently decrease their rate of photosynthesis and seal their stomata when exposed to a high VPD. Fungal and bacterial infections can be exacerbated by high humidity (Feng et al., 2023). Conversely, low humidity may affect crop development and productivity by causing excessive transpiration and water stress (Liliane & Mutengwa, 2020; Kamatchi et al., 2023). Water production and the general growth of crops such as tomatoes and cucumbers can be greatly impacted by these circumstances (Song et al., 2022).

2.5.3. Influence of edaphoclimatic factors on crop productivity and soil health

Aspects of agricultural production, such as germination, vegetative development, blooming, and yield formation, are influenced by interactions between edaphoclimatic variables (Hatfield & Prueger, 2015). Appropriate combinations of soil quality and climate are crucial for maximising crop yields and meeting the specified quality requirements (Challinor et al., 2014).

According to Lehmann et al. (2020), edaphoclimatic parameters are also essential for preserving the physical, chemical, and biological aspects of soil health. Good soil attributes, such as sufficient amount of organic matter, balanced nutrient levels, and suitable pH, encourage a variety of vibrant and dynamic soil microbial communities that are critical for the construction of soil structure, cycling of nutrients, and stimulation of plant growth (Lehmann & Kleber, 2015).

Mineralisation, immobilisation, and leaching are among the nutrient cycle activities regulated by soil characteristics and climate (Kallenbach et al., 2016). Ideal moisture and temperature levels encourage microbial activity, which accelerates the decomposition of organic waste and releases nutrients that are accessible to plants (Schimel & Schaeffer, 2012).

Climate variables, including temperature and precipitation, affect crop water availability, whereas soil texture, structure, and organic matter content affect the water-holding capacity and infiltration rates (Lal, 2020). Crop production and soil health depend on maintaining a suitable balance between water availability and demand (Steduto et al., 2012).

Salinisation, compaction, wind and water erosion, and other edaphoclimatic variables can contribute to soil deterioration (Lal, 2020). Poor soil management techniques, coupled with extreme weather events, including droughts or heavy rain, can intensify these processes and cause soil erosion, lower fertility, and decreased agricultural yield (Borrelli et al., 2017).

Several recent studies have emphasised the significance of edaphoclimatic factors and their interplay in influencing crop productivity and soil health. Recent research has examined the impacts of climatic conditions and soil characteristics on maize productivity, such as the amount of organic matter in the soil, availability of potassium, and amount of rainfall during the growth period (Feng et al., 2022; Dong et al., 2023).

Kindu et al. (2022) evaluated the anticipated effects of climate change on Ethiopia's wheat output. Their study emphasised that two important environmental restrictions that may reduce wheat yield are changes in temperature and rainfall patterns. Their study further suggested that the combination of late planting and extended maturing cultivars may greatly increase the grain output.

Habib-ur-Rahman et al. (2022) investigated at how climate change is affecting Asia's agricultural output, especially in areas where there is a shortage of food. According to their study, several climate-related extremes have a negative impact on farmers' livelihoods, including heat waves, droughts, storms, floods, and emerging insect pests. Additionally, the study predicted that by the mid-century (2040–2069), temperatures would have significantly increased, and there would be more unpredictable, intense rainfall, especially in Pakistan. For sustained production, they stressed the need to maximise climate-smart and resilient agricultural methods and technologies.

Verma et al. (2023) investigated how different wheat varieties' yields at different growth stages were affected by temperature stress. According to their research, the onset of high temperatures during crop growth, especially during grain filling, caused a significant reduction in almost all yield components measured. Grain filling is one of the main challenges when yield potential is constrained.

Zhang et al. (2022) studied the long-term effects of climate variables on wheat output in the top three wheat-producing regions of China. Their research showed that various climatic factors, including temperature and rainfall, have varying effects on wheat production in each province. For example, climate has a negative impact on wheat production in Henan Province and a positive impact on wheat production in Hebei Province.

MATERIALS AND METHODS

The study was conducted from 2021 to 2022, and study area was surveyed keeping in consideration the objectives of the study. The description of study area and detailed methods are as follows:

3.1. Study Area

For detailed investigation, a total of 6 study sites (3 each in Manipur and Mizoram) have been selected. The representative districts for study sites were Churachandpur in Manipur and Champhai in Mizoram. (Fig.3.1).

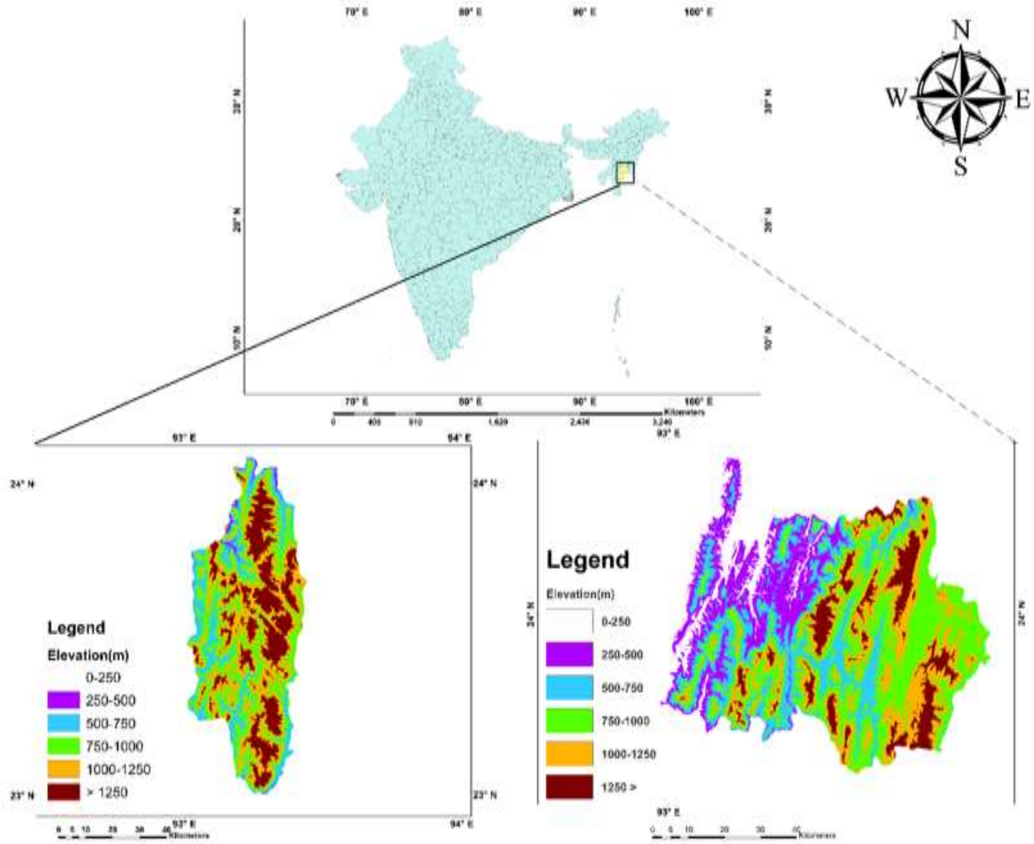


Fig 3.1: Location and Digital Elevation Map (DEM) of the study sites

3.1.1. Manipur

The state of Manipur is located between 92°58’23.422” E and 94°43’35.553” E and 23°49’45.530” N and 25°42’1.456” N and is bordered by Nagaland to the north, Myanmar to the southeast, Assam to the west and Mizoram to the southwest. With an area of 22,327 km², its altitude varies between 20 and 2994 m at the lowest and highest points above the mean sea level. As a valley surrounded by hill ranges, it has a subtropical temperate climate and an annual rainfall of 1,250–2,700 mm, with an annual average temperature of 14.5 °C to 38 °C (FSI, 2017, 2019). The state has nine hilly and tribal districts. With a population of 2,855,794 inhabitants, the urban and rural population proportions are 29.20% and 70.80%, respectively. The average population density of the state is 128 people/km² (FSI, 2017, 2019), with 3.41% and 40.88% representing Scheduled Castes and Tribes, respectively (Government of Manipur, 2019).

Churachandpur is located in the southwest of Manipur and borders the Senapati district to the north, the Chandel and Bishnupur districts to the east, Mizoram and Assam to the west, and Myanmar to the south. It is the largest district in Manipur, lies between 23°55' N and 24°30' N and 92°59' E and 93°50' E, and has an area of 4,570 square kilometers. With a population of 2,74,143, it is influenced by ethnic groups such as Chin, Mizo, Kuki, Zomi and Naga. Approximately 29,323 ha of the Churachandpur area are under rotational farming, and the jhum cycle has been shortened from five to seven years to four to five years (ICSSR, 2018).

Based on altitudinal gradients, three different sites were selected from the Churachandpur district of Manipur.

Table 1. Location of study sites in Churachandpur, Manipur

Altitudinal gradient (amsl)	**Site**	**Geo-coordinates**	**Altitude (m)**
Lower (<500 m)	Khuanggin (KG)	24°07'19" N 93°19'41" E	491
Middle (500-1000 m)	Enpum (EP)	24º02'48" N 93º28'21" E	987
Higher (<1000 m)	D. Hengkot (HK)	24°19'43 N 93°37'17" E	1430

3.1.1.1. Khuanggin

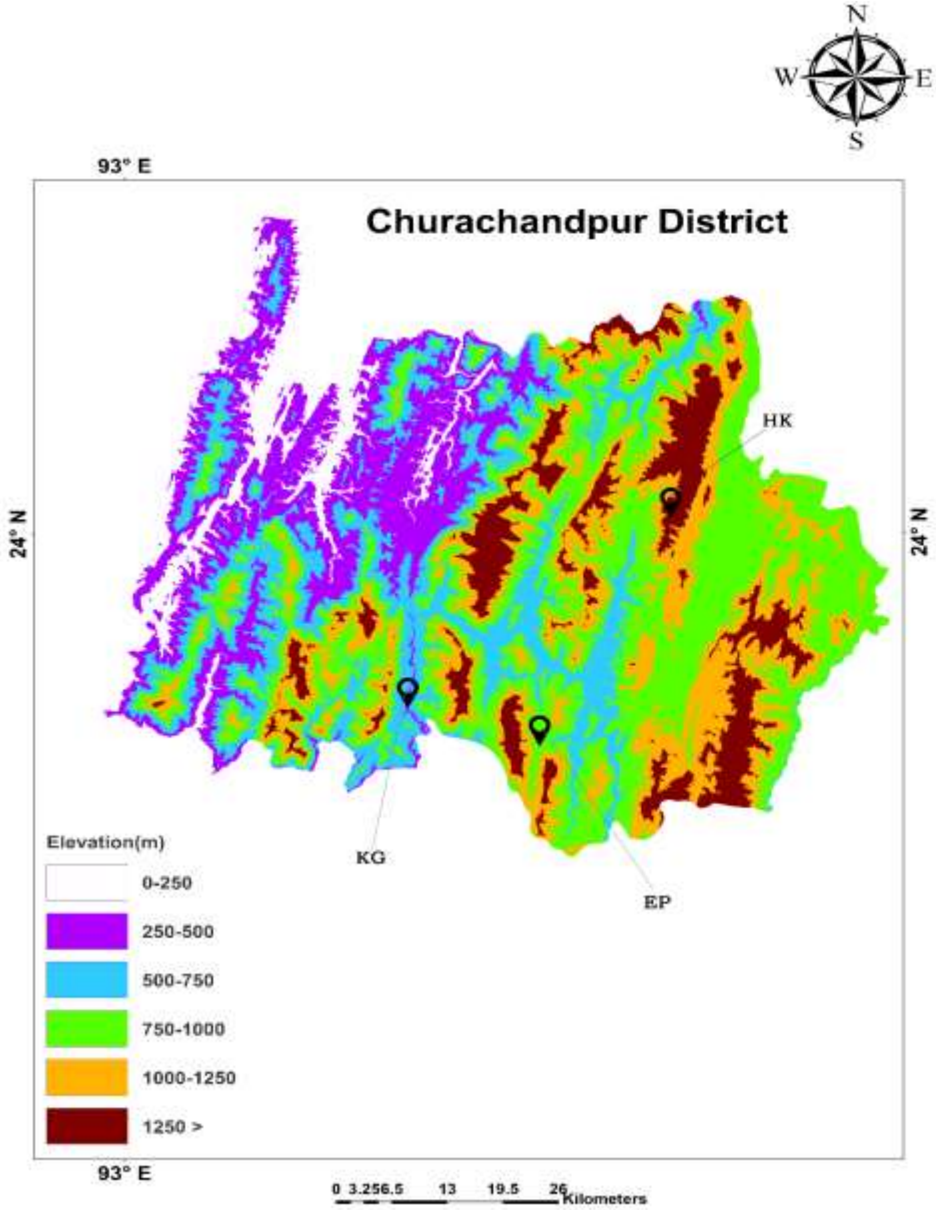
Khuanggin Village is located in the Thanlon subdivision of the Churachandpur district in Manipur approximately 80 km from the district headquarters. According to the Census 2011, the village has a total population of 230, comprising 112 males and 118 females. The literacy rate in Khuanggin was 64.78%, with 67.86% of males and 61.86% of females being literate. The village has around 30 houses, and the primary source of livelihood for its inhabitants is jhum cultivation. Other activities included charcoal processing, fishing, and hunting. The main crops grown in the village are pumpkin, maize, rice, cereals, chillies, taro, egg plants, and cucumbers, which are also used as cash crops. The current jhum site selected in Khuanggin Village is depicted in Plate 1.

3.1.1.2. Enpum

Enpum village, located in the Singngat subdivision of Churachandpur district in the state of Manipur, is situated approximately 44 km from the district headquarters in Churachandpur. According to the 2011 census, the village is home to a total population of 198 individuals, comprising 102 males and 96 females. The literacy rate in Enpum was 59.09%, with 64.71% of males and 53.13% of females being literate. There are approximately 32 houses in the village. Jhum cultivation serves as the primary occupation of the village, with all households actively engaged in this activity. The crops grown are primarily used as cash crops for the sustenance of farmers. The major crops grown in Enpum Village include rice, maize, cucumbers, pumpkins, melons, gingers, and sesame. The jhum field selected at Enpum Village is shown in Plate 3.

3.1.1.3. D. Hengkot

Hengkot Village is situated in the Churachandpur subdivision of Manipur's Churachandpur district, approximately 15 km from both the district and sub-district headquarters in Churachandpur. As per the 2011 census, the village has a population of 474 individuals, with an equal distribution of males and 237 females each. The village's literacy rate was 77.64%, with 78.06% of males and 77.22% of females being literate. The village comprises approximately 84 houses and its economy primarily relies on jhum cultivation. The major crops grown include rice, banana, maize, cucumber, okra, colocasia, and gourd. The jhum field selected for the study at



D. Hengkot Village is illustrated in Plate 5.

Fig. 3.2: DEM of Churachandpur District showing sampling sites

3.1.2. Mizoram

Mizoram is a landlocked state bordered by Bangladesh to the west, Myanmar to the east and south, Tripura to the northwest, Assam to the north, and Manipur to the northeast, with a total geographical area of 21,08,700 hectares (ha). It lies between 92°15'–93°29' E and 21°58'–24°35' N and averages 500–800 m above mean sea level. It has a humid tropical to sub-humid tropical climate, with an annual average temperature of 23°C and annual average rainfall of 2400 mm, and is characterised by rugged topography, steep mountain ranges, and interspersed valleys. The shifting cultivation and development activities attributed to 2017 resulted in a decrease in forest cover by 531 km² compared to 18,186 km² in 2015 (FSI, 2017, 2019). The population of Mizoram is 10,97,206 as per Census 2011, which is 0.09% of India's population, and is the third most important among the northeastern states, with a decadal pace of development of 23.48% (Government of Mizoram, 2021).

The Champhai area, commonly known as the 'Rice bowl of Mizoram', is located at about 23°29'06" N latitude and 93°16'45" E longitude on the eastern flank of the Aizawl hills (Mandaokar, 2004). Champhai is the highest-rugged region of Mizoram, flanking Myanmar, and it experiences slight border shifts from both sides. It is one of the third largest regions in Mizoram. It has a land area of 3185.83 km² and is divided into three blocks. The entire area has a geology with edges and valleys bounded by mountains, and has the highest altitude among the eight regions of Mizoram (Lalmalsawmzauva & Nayak, 2009). The average temperature in the winter months is between 10 °C and 15 °C, and in the summer months it can be between 23 °C and 26 °C. Some areas experience frost during the winter. The soil on the hills is generally porous, resulting in heavy leaching. In general, soils are acidic, with a pH between 4 and 5.5. Among the important nutrients, soil is poor in nitrogen, phosphorus, potash, zinc, boron, molybdenum, calcium, and magnesium. (Laltani, 1993). More than three-quarters of households in Champhai district (77%) are migrant farmers (Zaitinvawra & Kanagaraj, 2008) and have the largest cultivated area of 4,554 ha (Government of Mizoram, 2021)

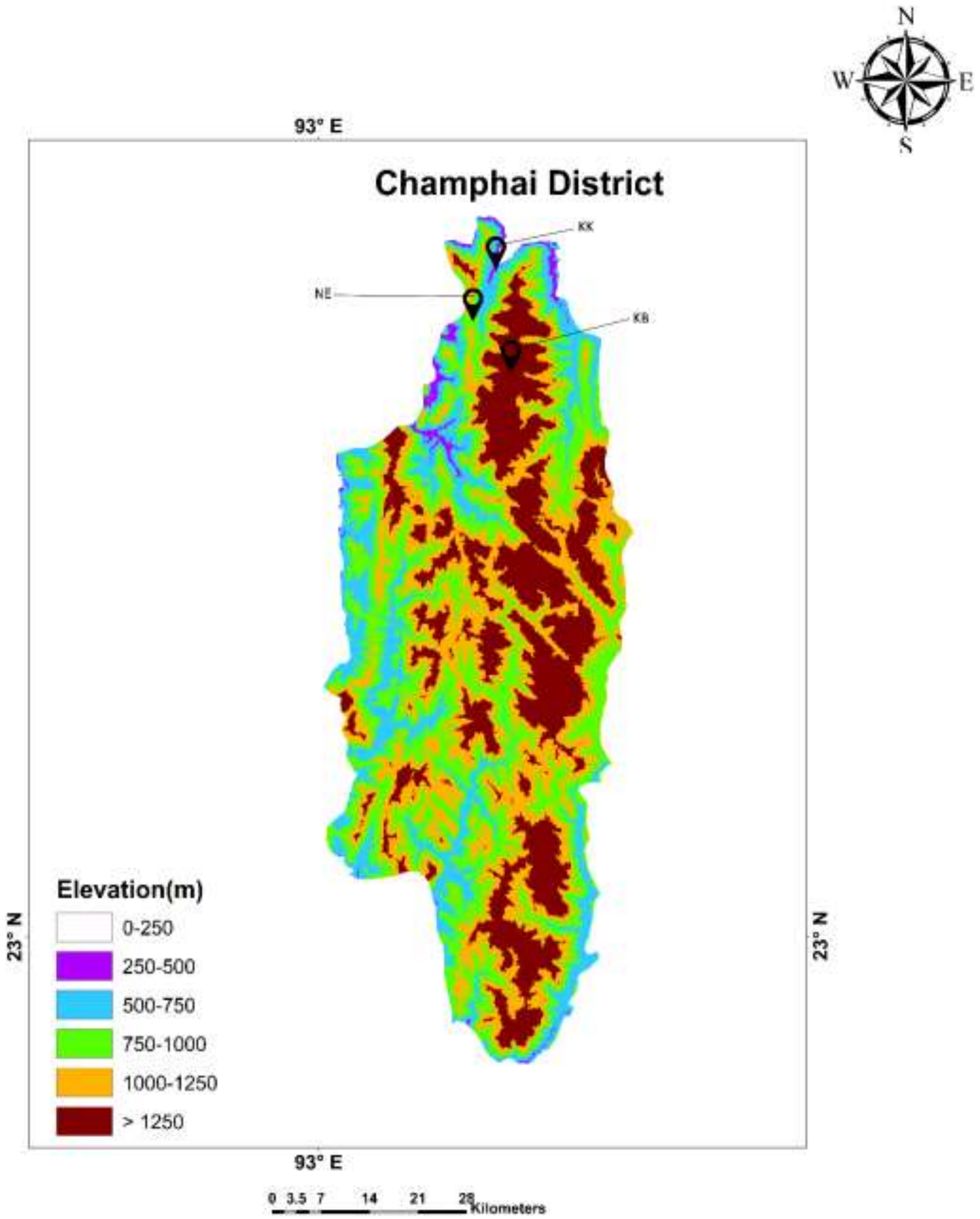


Fig 3.3: DEM of Champhai District showing sampling sites

Three sites in the Champhai district of Mizoram were chosen based on their altitudinal gradients; the details of these sites are outlined in Table 2.

Table 2. Location of study sites in Champhai, Mizoram

Elevation (amsl)	**Sites**	**Geo-coordinates**	**Altitude (m)**
Lower (<500 m)	Khawkawn (KK)	24°01'24"N 93°15'10"E	344
Middle (500-1000 m)	NE Khawdungsei (NE)	23°57'22"N 93°13'31"E	829
Higher (<1000 m)	Kawlbem (KB)	23°53'16"N 93°16'36"E	1579

3.1.2.1. Khawkawn

Khawkawn village, located in the Ngopa subdivision of the Champhai district in Mizoram, is 25 km from the sub-district headquarters of Ngopa. According to the Census (2011), the village has a total population of 908 people, with 452 males and 456 females. The workforce in Khawkawn is divided into the primary, secondary, and tertiary sectors, with the primary sector being the most prominent. The major crops cultivated in the village are pumpkins, maize, beans, cucumbers, and taro. The selected current jhum field at Khawkawn is highlighted in Plate 2.

3.1.2.2. NE Khawdungsei

NE Khawdungsei is a village situated in the Champhai District of Mizoram, India. It falls within the Ngopa R.D. Block. According to the 2011 census, the village has 400 households and a total population of 1825, with 929 males and 896 females. Similar to Khawkawn, the economic activities in NE Khawdungsei spanned the primary, secondary, and tertiary sectors. However, the primary occupation of the villagers is agriculture, particularly jhum cultivation. The main crops grown in the village are taro, maize, cucumbers, pumpkins, and beans. The jhum field selected for this study is shown in Plate 4.

3.1.2.3. Kawlbem

Kawlbem is a village located in the Ngopa subdivision of Champhai District in Mizoram, India. It is located 28 km from the sub-district headquarters in Ngopa. According to the Census (2011), with 268 households, the village has a total population of 1,479, with 735 males and 744 females. The primary occupation of the village is agriculture, and the majority of agricultural activity is jhum cultivation, and rice, maize, pumpkins, mustard, okra, egg plant, are the major crops cultivated in the village. The site chosen for the study in Kawlbem village is highlighted in Plate 6.

3.2. Data collection

3.2.1. Collection of soil samples

Soil samples were collected from selected jhum fields with elevation gradients of less than 500 meters above sea level (amsl), between 500-1000 m amsl, and greater than 1000 m amsl in the villages of Khawkawn (KK), NE Khawdungsei (NE), and Kawlbem (KB) in Champhai district, and in Khuanggin (KG), Enpum (EP), and D. Hengkot (HK) in Churachandpur district. The soil samples were also collected based on the depth of the soil, specifically at 0-15 cm and 15-30 cm, and based on the seasons, which were pre-monsoon (March – June), monsoon (July–October), and post-monsoon (November – February). Soil samples were collected from five different areas of the same field and mixed thoroughly to produce a composite sample weighing approximately 1 kg, to obtain a representative soil sample from the site.

The soil samples were placed in polyethylene bags and meticulously labelled with all pertinent details, such as the site and depth of sampling. Subsequently, the samples were left to dry in air before their physicochemical characteristics were examined.

3.3. Soil analysis

After a weeklong period of air-drying, the soil samples were subjected to the removal of any remaining residues, roots, shoots, stones, and other debris. Subsequently, the soil samples were crushed and sieved through a 2-millimetre hole size sieve, followed by storage for subsequent analysis.

Soil samples were analysed at the Indian Council of Agricultural Research – Research Complex, Manipur Centre (ICAR-RC), and Lamphelpat. The physical and chemical properties of the soil samples were analysed, including soil texture, pH, electrical conductivity (EC), bulk density (BD), soil moisture content (SMC), water-holding capacity (WHC), soil organic carbon (SOC), and available nitrogen (Avail. N), available phosphorus (Avail. P), available potassium (Avail. K), and exchangeable calcium (Exch. Ca), exchangeable sodium (Exch. Na) and exchangeable magnesium (Exch. Mg).

3.3.1. Soil texture

The method employed by Anderson and Ingram (1993) was used to evaluate soil textures. Fifty grams of air-dried soil samples were weighed. Disperse the soil samples with the dispersing solution (50 g of sodium hexametaphosphate, $Na_6(PO_3)_6$ in deionised water and dilute to 1 L to make a 5% dispersion solution). The dispersed soil was then transferred to a sedimentation cylinder and made up to a volume of 1 L using distilled water. The suspension was shaken from top to bottom, or with a plunger, approximately 20 times per minute. The hydrometer readings were recorded after 4 min and 2 h by slowly lowering the hydrometer to suspension. The temperature of the suspension was recorded, and thermometer correction was applied to the hydrometer readings. For the blank sample, the same procedure as described above was followed without soil samples.

Calculations:

$$\% \text{ (Silt+Clay)} = \frac{\text{CHMR after 4 min - Blank}}{\text{Weight of soil}} \text{ X } 100$$

$$\% \text{ Clay} = \frac{\text{CHMR after 2 hrs-Blank}}{\text{Weight of soil}} \text{ X } 100$$

% silt=% (silt+clay)-% clay

% sand=100-% (silt+clay)

3.3.2. Soil Moisture Content (%)

Soil moisture content (SMC) can be expressed as the ratio of water mass to the dry weight of the soil sample. The SMC was determined by a gravimetric method, in which 10 g of the fresh soil sample was placed in a hot air oven at 105 °C for approximately 48 h or until the soil reached a constant weight.

Calculation:

$$\text{Soil Moisture content (\%)} = \frac{\text{Fresh weight-dry weight}}{\text{Dry weight}} \text{ X } 100$$

3.3.3. Water holding capacity (%)

Bernard's (1963) modified funnel method was used to determine the water-holding capacity (WHC) of soils. Soil samples (25 g) were collected in a 100 ml funnel with a layer of filter paper at the bottom. The funnel was mounted on a 500 ml graduated cylinder. Water (100 ml) was poured into the soil samples and allowed to drain for 72 hours. The volume of the water collected from the cylinder was recorded.

Calculation:

WHC = (a - b) X 100 %

Where

a is the volume of water added to the soil and funnel.

b is the amount of water collected after 72 h.

3.3.4. Bulk density (g/cm^3)

The bulk density of soil samples was estimated using the method described by Anderson and Ingram (1993). Remove 1-2 cm of the surface soil from the sampling location and smooth the area. A thin sheet metal tube with a diameter of 5 cm and known weight (W_1) and volume (V) of 5 cm was placed on the soil surface. The soil around the pipe was dug and the soil beneath the pipe base was cut away. The excess soil was trimmed from the end of the pipe. The samples were dried at 105 °C for two days and weighed (W_2).

Calculation:

Volume of corer (V) = $\pi r^2 h$

Where,

π= 3.14

r = the radius of the corer

h = the height of the corer

$$\text{Bulk Density } (g/cm^3) = \frac{W_2 - W_1}{V}$$

Where,

W_1- weight of soil before oven drying + corer

W_2- weight of oven-dried soil + corer

V- volume of the corer

3.3.5. Soil pH

The pH of the soil samples was measured at a soil-to-water ratio of 1:2. The collected soil (20 g) was removed and 40 ml of distilled water was placed in a beaker. The soil-water mixture was magnetically stirred for 20 min. The pH was measured using a digital pH meter.

3.3.6. Electrical conductivity (dSm^{-1})

The conductivities of the soil samples were determined using an electrical conductivity (EC) meter. Soil samples (25 g) were mixed with 50 mL of deionised water until the mixture became muddy. The probe was then inserted into the beaker, and the measured values were recorded using a Deci Siemens per meter (dSm^{-1}).

3.3.7. Soil Organic carbon (%)

The soil organic carbon (SOC) content of the soil samples was determined using the method described by Walkey and Black (1934).

Procedure:

a) Soil samples (0.5 g) were placed in a 500 ml volumetric flask.
b) To this solution, 10 ml of $K2Cr2O_7$ was added, followed by 20 ml of conc. H_2SO_4.
c) The mixture was then swirled gently to disperse the soil in the dichromate solution.
d) The flask was allowed to stand without disturbance for 20 minutes (in the dark).
e) Subsequently, 10 ml of H_3PO_4 (orthophosphoric acid) was added to 150-200 ml of distilled water.
f) 0.2 g NaF (Sodium fluoride) is also added to the mixture.
g) 2 - 3 ml of Diphenylamine indicator was then added
h) The sample was then titrated with ammonium iron sulphate solution until the colour changed from dark blue to bottle green.
i) Blank titrations were performed simultaneously.

Calculation:

The soil organic carbon content (%) of the soil samples was calculated using the following equation:

$$\text{Organic carbon \% in soil} = \frac{10\ (B\text{-}S)}{B} \times 0.003 \times \frac{100}{\text{wt. of sample (g)}}$$

OR

$$\text{Organic carbon \% in soil} = \frac{10 \times 1\ (B - S) \times 0.003 \times 100}{B \times \text{wt. of sample (g)}}$$

Where,

B - volume of ammonium ferrous sulphate used in blank titration

S- volume of ammonium ferrous sulphate for soul samples

3.3.8. Available Nitrogen (kg/ha)

The nitrogen content of the soil samples was determined using the Kjeldahl method (Subbiah & Asija, 1956). The Kjeldahl method can be used to precisely determine available nitrogen in soil samples. The determination method involved three consecutive phases.

1. Digestion of organic material to convert nitrogen into HNO_3.
2. Distillation of ammonia is released into the absorbent surface or medium.
3. Titration of ammonia formed during digestion

Digestion: This is the decomposition of nitrogen in the organic samples using conc. Acid solution. This was performed by boiling a homogeneous sample in a conc. H_2SO_4 acid. The final product was an ammonium sulphate solution.

$$2C_6H_3(OH)\,NH_2COO + 26\,H_2SO_4 \rightarrow (NH_4)_2SO_4 + 25\,SO_2 + 14\,CO_2 + 28H_2O$$

Distillation: An excess base (NaOH) was added to the digested acid mixture to convert NH_4^+ to NH3, followed by boiling and condensation of NH_3 gas in the receiving solution.

$$(NH_4)_2SO_4 + 2\,NaOH \rightarrow Na_2SO_4 + 2\,NH_3 + 2\,H_2O$$

Titration: When using boric acid (H_3BO_3) as a collection solution instead of a standardised mineral acid, boric acid captures ammonia gas and forms an ammonium borate complex, which results in a colour change in the collection solution.

$$NH_3 + H_3BO_3 \rightarrow NH_4^+{:}H_2BO_3^- + H_3BO_3$$

$$NH_4^+{:}H_2BO_3^- + H_2SO_4 \rightarrow (NH_4SO_4)_2 + 2H_3BO_3$$

The addition of sulphuric acid neutralised the ammonium borate complex and produced a reverse colour change.

Calculation:

$$N\% = \frac{14 \text{ X Normality of acid X Titrant value of burette reading X } 100}{\text{Soil sample weight X } 1000}$$

$$N\ (kg/ha) = \frac{14 \text{ X Normality of acid X Titrant value of burette reading X } 2.24 \text{ X } 10^6}{\text{Soil sample weight X } 1000}$$

3.3.9. Available phosphorus (kg/ha)

The Bray-2 method (Bray & Kurtz, 1954) was used to estimate available phosphorus. Five grams of the soil sample was placed in a 150 ml Erlenmeyer flask, and 35 ml of Bray-2 solution was added. Activated carbon (2 g) was added and the mixture was stirred for approximately 10 min. The extract was filtered through Whatman filter paper (No. 1). Five millilitres of the filtrate was placed in a 50 ml volumetric flask, and 5 ml of the mixed reagent (ascorbic acid) was added to the 50 ml mark with distilled water. Spectrophotometer readings were recorded at 882 nm after 20 min of colour development.

Preparation of Standards for available phosphorus

i) Preparation of a 50 ppm P-solution

- 0.296 g of KH_2PO_4 (potassium dihydrogen orthophosphate, AR grade) was placed in a 1000 ml volumetric flask.
- Then, 400 ml of distilled water and 25 ml of 7N H_2SO_4 were added.
- Distilled water was added to a 1000 ml mark volumetric flask.

7N H_2SO_4

- 19.5 ml of conc. H_2SO_4 in 100 ml in a volumetric flask.
- Make up the volume to the 100 ml mark with distilled water.

$S_1V_1 = S_2V_2$

$=< 36N \times V1 = 7N \times 100$ ml

$=< V_1 = \frac{7 \times 100}{36} = 19.444 \sim 19.5$ ml

ii) 2 ppm P-solution

- Take 20 ml of 50 ppm P solution in 500 ml in a volumetric flask.
- The volume was increased to 500 ml using distilled water.

$S_1V_1 = S_2V_2$

$=< 50 \text{ ppm} \times V_1 = 2 \text{ ppm} \times 500$ ml

$$=< V_1 = \frac{2 \text{ x } 500}{50} = 20 \text{ ml}$$

Calculation:

The final readings were calculated using a linear equation (using standard readings) and expressed as parts per million (ppm). This value was multiplied by the dilution factor.

Dilution factor:

Soil sample weight = 5 g

Amount of Bray-2 solution = 35 ml (extractant)

Amount of filtrate = 5 ml (or 2 ml)

Final volume with mixed reagent = 50 ml or 25 ml.

$$\text{Dilution factor} = \frac{35}{5} \text{ X } \frac{25}{2} = 70$$

∴ Final reading = x X 70

where x is the reading calculated using the linear expression equation.

$$\text{Avail. P (kg/ha)} = \frac{\text{ppm X Vol. of extractant in ml X make up volume in ml X 2.24}}{\text{weight of oven dry soil in g X volume of soil extract in ml}}$$

3.3.10. Available Potassium (kg/ha)

Available potassium in the soil samples was determined using a normal neutral 1N ammonium acetate extractant and a flame photometer (Hanway & Heidal, 1952).

Procedure:

1. 1N ammonium acetate (7.0 pH): 77.08 g of ammonium acetate is dissolved in approximately 800 mL of distilled water, and the pH was adjusted to 7.0, with either ammonium hydroxide or acetic acid, to achieve a final volume of 1 L.
2. Soil samples (5 g) were placed in Erlenmeyer flasks.
3. Then, 25 ml of 1N ammonium acetate solution was added to the flask and the soil samples.

4. The contents were shaken using a mechanical shaker for 30 minutes.
5. The solution was then filtered using Whatman #42 filter paper.
6. The measured values (ppm) were determined using a flame photometer.

Calculation:

The measured values determined using the flame photometer are expressed in ppm. Therefore, the final value was determined by using a dilution factor.

Initial soil sample weight = 5 g

Volume of ammonium acetate = 25 ml

$$\text{Dilution factor} = \frac{25}{5} = 5$$

Final reading = *x* ppm X 5

$$\text{Avail. K (kg/ha)} = \frac{\text{Conc. of K (ppm) X Vol. of extractant X 2.24 X 1.21}}{\text{Weight of soil (g)}}$$

3.3.11. Exchangeable Sodium (cmol(p^+)/kg)

Procedure:

1. Accurately measure out 2.52 grams of sodium chloride, which has been accurately measured, dried at 120°C to a constant mass, and cooled to room temperature. The weighed salt to a 250-ml beaker and dissolved in approximately 100 ml of water. Next, 10 ml of concentrated hydrochloric acid was added to the solution. The mixture was transferred quantitatively to a one-litre, one-mark volumetric flask and diluted to the correct volume mark. The solution was thoroughly mixed and stored in a polyethylene bottle. This solution contained 1 mg/ml sodium.
2. In a 100-milliliter volumetric flask, 10 mL of the standard solution was mixed with 2 mL of concentrated hydrochloric acid, and the flask was filled to its designated volume. This solution had a concentration of 100 mg/mL of sodium. Subsequently, dilute 1, 2, 3, 4, and 5 ml of the aforementioned solution to a total volume of 100 ml in 100 ml volumetric flasks, numbered as 1, 2, 3, 4, and 5, respectively.
3. The mineral sample (0.2 g) was accurately weighed and transferred to a 100-ml beaker. Subsequently, 5 ml of concentrated hydrochloric acid, 5 ml of concentrated nitric acid, and 10 ml of water were added. The mixture was boiled for 30–40 min

until the reaction was complete and then transferred to a 100-ml volumetric flask. Transfer the washings and make up the volume to the mark.

4. The Flame Photometer was calibrated before the solutions were aspirated to determine the Na^+ ion concentrations.
5. Undiluted solutions, if galvanometer readings surpass the maximum value in the standard curve, should be appropriately diluted, followed by the addition of 2 ml of hydrochloric acid per 100 ml, and then aspirated.
6. A reagent blank was continuously employed throughout the estimation process. It is advisable to examine the standard curve before or after aspiration of the test solution.

Calculation:

$$\text{Exch. Na}^+(\text{ppm}) = \frac{\text{Na}^+ \text{ conc. from Std. curve (ppm) X Vol. of extractant (ml)}}{\text{Wt. of soil (g)}}$$

$$\text{Exch. Na}^+(\text{cmol}(\text{p}^+)/\text{kg soil}) = \frac{\text{Ex. Na}^+\text{ppm}}{23 \text{ x } 10}$$

3.3.12. Exchangeable Calcium and Exchangeable Magnesium (cmol(p^+)/kg)

The exchangeable Ca and Mg content of the soil was determined using an Atomic Absorption Spectrometer (AAS).

Procedure:

1) One gram of the sieved soil sample was weighed and placed in a crucible.
2) The crucible was then placed in a muffle furnace at 550 °C for 4 h.
3) After 4 h, the crucible was removed from the furnace, and 10 ml of 2N HCl was added to the soil sample and left to rest for 30 min.
4) The sample solution was passed through Whatman #42 filter paper into a 50 ml volumetric flask.
5) Distilled water was added to the filtrate to reach a 50 ml mark.
6) The readings of the samples were then recorded in the AAS and reported in ppm.

Calculations:

Exchangeable calcium content of the soil samples was calculated using the following formula:

$$\text{Exch. Ca}^{2+}\text{ (ppm)} = \frac{\text{Ca}^{2+}\text{conc. from std curve (ppm) X Vol. of extractant (ml)}}{\text{Wt. of soil (g)}}$$

$$\text{Exch. Ca}^{2+}\{\text{me/100g or (p}^{+}\text{)/kg soil}\} = \frac{\text{Exch. Ca}^{2+}\text{(ppm)}}{20 \text{ x } 10}$$

Exchangeable Mg content of the soil samples was calculated using the following formula:

$$\text{Exch. Mg}^{2+}\text{ (ppm)} = \frac{\text{Mg}^{2+}\text{conc. from std curve (ppm) X Vol. of extractant (ml)}}{\text{Wt. of soil (g)}}$$

$$\text{Exch. Mg}^{2+}\{\text{me/100 or cmol (p}^{+}\text{)/kg soil}\} = \frac{\text{Exch. Mg}^{2+}\text{(ppm)}}{12 \text{ x } 10}$$

3.4. Plant growth and yield analysis

3.4.1. Maize growth and yield

3.4.1.1. Number of leaves per plant: Five maize plants were selected from each site, and the number of leaves was counted and recorded at 30, 60, and 90 days and at maturity of the plant.

3.4.1.2. Maize height: From each site, the maize height of the selected maize plant was measured using a linear scale at 30, 60, and 90 days and at maturity and recorded in centimetres (cm).

3.4.1.3. Leaf Area Index (LAI): The leaf area index (LAI) of the five selected maize and cucumber plants were recorded during the pre-monsoon, monsoon, and post monsoon seasons. LAI was calculated using the following formula:

$$\text{LAI} = \frac{\text{Leaf Area}}{\text{Ground area}}$$

3.4.1.4. Number of corns per plants: The average number of cobs per plant was determined by counting the number of cobs on five randomly selected plants from each plot.

3.4.1.5. Weight of corn: The weights of five maize corn samples (g) at maturity were systematically recorded for each site.

3.4.1.6. Biomass: Upon reaching maturity, the aboveground biomass of the plant was harvested and cut at the ground level. Subsequently, it was fragmented into smaller pieces and heated in a hot air oven at 70°C until a consistent dry weight was achieved. The weight of the dried plant material was measured and recorded in grams (g).

3.4.1.7. Test weight: A total of 1000 grains were tallied from each sample, and their individual weights in grams were recorded.

3.4.1.8. Grain yield: The grain yield of maize for each site was calculated by using the formula,

$$\text{Grain yield (kg/ha)} = \frac{\text{1 ha X yield per plot (kg)}}{\text{Net area of plot}}$$

3.4.1.9. Harvest Index: The harvest index of maize for each site was calculated by using the formula,

$$\text{Harvest Index \%} = \frac{\text{Economic yield (grains)}}{\text{Biomass}} \text{ X100}$$

3.4.2. Cucumber growth and yield

3.4.2.1. Vine length: The vine length of the five selected cucumber plants was measured at 30, 60, and 90 days of maturity from each site, and their lengths were recorded in centimetres (cm).

3.4.2.2 Leaf Area Index (LAI): The leaf area index (LAI) of the five selected maize and cucumber plants were recorded at 30, 60, and 90 days and at maturity.

3.4.2.3 Number of leaves per plant: Five cucumber plants were selected from each site, and the number of leaves was counted and recorded at 30, 60, and 90 days and at maturity of the plant.

3.4.2.4. Number of fruits per plant: The number of fruits produced per plant was recorded for the five selected plants.

3.4.2.5. Weight of fruit: The weights of the five cucumber fruits at maturity were systematically recorded at each site.

3.4.2.6 Fruit length: The lengths of selected fruits were weighed and recorded.

3.4.2.7. Yield (kg/ha): Cucumber yield (kg/ha) was estimated and recorded.

3.4.2.8. Plant biomass (g): Upon reaching maturity, the aboveground biomass of the plants was harvested and cut at the ground level. Subsequently, it was fragmented into smaller pieces and heated in a hot air oven at 70°C until a consistent dry weight was achieved. The weight of the dried plant material was measured and recorded in grams (g).

3.4.2.9. Harvest Index (%): The harvest index for cucumber for each site was calculated using the formula,

$$\text{Harvest Index \%} = \frac{\text{Economic yield (fruits)}}{\text{Biomass}} \text{ X100}$$

3.5. Documentation of crops: For each site, the crops that were planted at the jhum fields were identified and documented.

3.6. Statistical analysis

Statistical analysis was conducted using SPSS 27. The data were analysed to determine their frequency distribution, including the mean and standard error of the mean (SEM). Soil parameters were examined for their correlation using the Pearson Correlation Coefficient, with *p*-values set at <0.05, unless otherwise stated. This was followed by two-way analysis of variance (ANOVA) to determine the relationship between altitude, season, and soil parameters. The post-hoc Fisher's least significant difference (LSD) test was employed to determine the significance of variations in soil characteristics in relation to altitude and season. Graphs were created using GraphPad Prism 10.1.0.

CHAPTER 4

RESULTS

4.1. Climatic data

The monthly average temperature and rainfall in Churachandpur are listed in Table 4.1. The table shows that Churachandpur has experienced a wide range of temperatures and rainfall patterns across different months. The highest average temperature was recorded in June at 32.5°C, while the lowest average temperature was observed in January at 18°C. This indicates that the region has experienced hot summers and cool winters. In terms of rainfall, August received the highest amount of precipitation (200.9 mm), followed by June (191 mm), and July (185.8 mm). The lowest amount of rainfall was recorded in February at only 2.5 mm.

Table 4.1.1: Monthly average temperature and rainfall of Churachandpur during the study period

Month	Temperature (ºC)	Rainfall (mm)
January	18	13.4
February	20.5	2.5
March	26	25.4
April	28	44.5
May	25	64.5
June	32.5	191
July	30.5	185.8
August	31	200.9
September	28	88.5
October	29	45
November	22	4.6
December	19.5	34.5

The monthly average temperature and rainfall data for Champhai, a district in Mizoram, India, are listed in Table 4.1.2. The data gathered from the India

Meteorological Department (IMD) and the Department of Economics and Statistics; Government of Mizoram revealed that Champhai enjoyed a milder temperature range than Churachandpur did. The highest average temperature was recorded in September at 21.3°C, while the lowest average temperature was noted in January at 9.7°C. This indicates that Champhai has a significantly colder temperature throughout the year, with moderate summers and cold winters. The rainfall patterns in Champhai differ significantly from those in Churachandpur. The monsoon season in Champhai is higher during June, July, and August getting the maximum amounts of rainfall at 275.2 mm, 272.9 mm, and 255.4 mm, respectively. In comparison, the dry season in Champhai is more evident, with February having the least amount of rainfall at just 0.3 mm.

Table 4.1.2: Monthly average temperature and rainfall of Champhai during the study period

Month	Temperature (°C)	Rainfall (mm)
January	9.7	2.1
February	13.05	0.3
March	18	10.6
April	20.2	27.9
May	20.8	48.3
June	20.65	275.2
July	21.15	272.9
August	21	255.4
September	21.3	160
October	20.35	70.7
November	17.05	21.1
December	13.3	67.6

4.2. Mode of operation

The mode of operation in jhum fields exhibited a high degree of consistency across the six study sites in Churachandpur (KG, EP, and HK) and Champhai (KK, NE, and KB) districts of Manipur and Mizoram, India. The size of the jhum fields showed slight variations, ranging from 1 ha to 1.4 ha, with HK and KB having the largest fields at 1.4 ha and 1.3 ha, respectively. The cultivation process followed a similar pattern in both districts, beginning with the slashing of the vegetation in December. The slashed vegetation, including plants, branches, twigs, and leaves, was left sun-dry for several weeks before being subjected to burning from January to February. This burning process serves multiple purposes such as clearing land, releasing nutrients into the soil, and reducing the risk of pest and disease infestation.

Following the burning process, land preparation was carried out in February-March, which involved clearing the burned debris and loosening the soil using traditional tools such as hoes, machetes, and axes. The timing of seed sowing varied slightly among the sites, with most sites sowed in March, EP sowed in March-April, and NE and KB sowed in April. This variation in sowing time may be influenced by factors such as local climate, soil moisture content, and the availability of labour.

The number of seeds sown per pit was consistent for maize (3-4 seeds) across all sites, indicating a common practice aimed at optimising plant density and yield. However, cucumber seed sowing varied slightly, with 2-3 seeds per pit in KG, KK, and KB, and 2-4 seeds per pit in EP, HK, and NE. This variation in cucumber seed sowing may be attributed to differences in local preferences, market demand, or seed availability.

The tools used for cultivation were similar across all sites, with hoes and machetes being the primary tools in KG and HK, whereas an axe was an additional tool used at the other sites. These traditional tools are well-suited to the rugged terrain and small-scale nature of jhum cultivation. The number of people engaged in the cultivation process was either two or three, with larger field sizes in HK, KK, and KB requiring three people, whereas smaller fields in KG, EP, and NE required only two people. This variation in labour requirements may be influenced by factors such as the availability of family labour, the complexity of the terrain, and the intensity of the cultivation practices.

The jhum fields in Churachandpur and Champhai districts operate in a remarkably consistent manner. This consistency is evident across various aspects, such as field size, seed sowing schedules, and labour requirements, with only minor variations observed. The uniformity of these cultivation practices can be traced back to the shared cultural and ecological contexts of the region. Furthermore, jhum cultivators commonly face challenges such as soil erosion, declining soil fertility, and the necessity for sustainable land management practices, which could also contribute to this consistency.

4.3. Crop Composition

The crop composition of the jhum fields in the study sites of Churachandpur (KG, EP, and HK) and Champhai (KK, NE, and KB) districts of Mizoram, India, showed both similarities and variations. The tables (4.3.1 to 4.3.6) provide a comprehensive list of the crops grown at each site, along with their scientific names, common names, families, and parts used.

Cucurbitaceae and Poaceae were the most common families represented in crop composition across all sites. *Cucumis sativus* (cucumber) and *Zea mays* (maize) were the two crops consistently grown at all the six sites. Cucumber fruits and corn are the primary components of these crops. The prevalence of these crops at all sites suggests their importance to the local diet and suitability for cultivation in the jhum system.

Table 4.2.1: Mode of operation in selected jhum fields of Churachandpur and Champhai

Site	Size (ha)	Slashing	Burning	Land preparation	Seed sowing	No. of seeds/pit		Tools used	No. of workers
						Maize	Cucumber		
KG	1	December	Jan-Feb	Feb-Mar	March	3-4	2-3	Hoe, machete	2
EP	1.2	December	Jan-Feb	Feb-Mar	Mar-Apr	3-4	2-4	Hoe, axe, machete	2
HK	1.4	December	Jan-Feb	Feb-Mar	March	3-4	2-4	Hoe, machete	3
KK	1	December	Jan-Feb	Feb-Mar	March	3-4	2-3	Hoe, axe, machete	3
NE	1.2	December	Jan-Feb	Feb-Mar	April	3-4	2-4	Hoe, axe, machete	2
KB	1.3	December	Jan-Feb	Feb-Mar	April	3-4	2-3	Hoe, axe, machete	3

Table 4.3.1: Crop composition of site KG

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Solanum melongena*	Brinjal	Solanaceae	Leaves, fruits
4	*Abelmoschus esculentus*	Okra	Malvaceae	Fruits
5	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
6	*Glycine max*	Soyabeans	Fabaceae	Seeds
7	*Cucurbita pepo*	Pumpkin	Cucurbitaceae	Leaves, vines, flowers, fruits
8	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber

Table 4.3.2: Crop composition of site EP

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Citrullus lanatus*	Watermelon	Cucurbitaceae	Fruits
4	*Solanum melongena*	Brinjal	Solanaceae	Leaves, fruits
5	*Abelmoschus esculentus*	Okra	Malvaceae	Fruits
6	*Capsicum annum*	Chili pepper	Solanaceae	Fruits
7	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
8	*Cucurbita pepo*	Pumpkin	Cucurbitaceae	Leaves, vines, flowers, fruits
9	*Oryza sativa*	Rice	Poaceae	Seeds
10	*Sesamum radiatum*	Sesame	Pedaliaceae	Seeds
11	*Zingiber officinale*	Ginger	Zingiberaceae	Tuber
12	*Momordica charantia*	Bitter gourd	Cucurbitaceae	Leaves, fruits
13	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber

Table 4.3.3: Crop composition of site HK

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Citrullus lanatus*	Watermelon	Cucurbitaceae	Fruits
4	*Capsicum annum*	Chili pepper	Solanaceae	Fruits
5	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
6	*Cucurbita pepo*	Pumpkin	Cucurbitaceae	Leaves, vines, flowers, fruits
7	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber
8	*Oryza sativa*	Rice	Poaceae	Seeds

Table 4.3.4: Crop composition of site KK

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Zingiber officinale*	Ginger	Zingiberaceae	Tuber
4	*Capsicum annum*	Chili pepper	Solanaceae	Fruits
5	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
6	*Cucurbita pepo*	Pumpkin	Cucurbitaceae	Leaves, vines, flowers, fruits
7	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber
8	*Smallanthus sonchifolius*	Ground apple	Asteraceae	Tuber

Table 4.3.5: Crop composition of site NE

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Citrullus lanatus*	Watermelon	Cucurbitaceae	Fruits
4	*Solanum melongena*	Brinjal	Solanaceae	Leaves, fruits
5	*Abelmoschus esculentus*	Okra	Malvaceae	Fruits
6	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
7	*Zingiber officinale*	Ginger	Zingiberaceae	Tuber
8	*Momordica charantia*	Bitter gourd	Cucurbitaceae	Leaves, fruits
9	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber

Table 4.3.6: Crop composition of site KB

Sl. No.	Scientific Name	Common Name	Family	Parts used
1	*Cucumis sativus*	Cucumber	Cucurbitaceae	Fruits
2	*Zea mays*	Maize	Poaceae	Corn
3	*Capsicum annum*	Chili pepper	Solanaceae	Fruits
4	*Phaseolus vulgaris L.*	Beans	Fabaceae	Leaves, fruits
5	*Cucurbita pepo*	Pumpkin	Cucurbitaceae	Leaves, vines, flowers, fruits
6	*Colocasia esculenta*	Taro	Araceae	Petioles, tuber
7	*Alocasia foricata*	Baibing	Araceae	Spadix

Other common crops found at most sites include *Phaseolus vulgaris* L. (beans), *Cucurbita pepo* (pumpkin), and *Colocasia esculenta* (taro). Beans and pumpkins were grown for their leaves and fruits, whereas taro was cultivated for its petioles and tubers. Some crops are specific to certain sites, reflecting local preferences and agroecological conditions. For example, *Solanum melongena* (brinjal) was grown on KG, EP, and NE, whereas *Abelmoschus esculentus* (okra) was cultivated on KG, EP, and NE. *Citrullus lanatus* (watermelon) was found in EP, HK, and NE, and *Zingiber officinale* (ginger) was grown in EP, KK, and KB. Some unique crops were also observed at individual sites, such as *Glycine max* (soybean) in KG, *Sesamum radiatum* (sesame) in EP, *Smallanthus sonchifolius* (ground apple) in KK, and *Alocasia foricata* (baibing) in KB.

The diversity of crops grown in the jhum fields across the study sites highlights the importance of the jhum system in maintaining agrobiodiversity and supporting local food security. The cultivation of a wide range of crops also helps in risk mitigation because the failure of one crop can be compensated for by others.

4.4. Soil analysis

The soil analysis covering jhum fields of Churachandpur and Champhai along an altitudinal gradient and the results of soil analysis are further divided into two broad sub-sections – physical properties and chemical properties of soil. Physical properties such as soil texture, soil moisture content (SMC), water holding capacity (WHC), and bulk density (BD) are discussed, including parameters such as pH, electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (Avail. N), available phosphorus (Avail. P), available potassium (Avail. K), exchangeable sodium (Exch. Na), exchangeable calcium (Exch. Ca) and exchangeable magnesium (Exch. Mg).

4.4.1. Physical properties of soil

4.4.1.1. Sand

In Churachandpur at site KG, the sand content at the top layer (0-15 cm depth) ranges from 79.51 ± 0.02% (pre-monsoon) season to 82.75 ± 0.03% (monsoon) (Table 4.2.1). At the subsurface soil (15-30 cm depth) the sand content ranged from 78.24 ± 0.02% (pre-monsoon) to 80.68 ± 0.01% (monsoon) (Fig 4.4.1) (Table 4.4.1).

At site EP, the sand content at top layer ranged from 71.06 ± 0.30% (pre-monsoon) to 84.74 ± 0.03% (monsoon) (Fig 4.4.1) (Table 4.4.2). At the subsurface, the sand content ranged from 69.15 ± 0.16% (pre-monsoon) to 86.17 ± 0.04% (monsoon) (Fig 4.4.2) (Table 4.4.2).

At site HK, the sand content at the top layer ranged from 63.17 ± 0.03% (post monsoon) to 85.71 ± 0.01% (monsoon) (Fig 4.4.1) (Table 4.4.3). At the subsurface layer, the sand content ranged from 68.89 ± 0.11% (post monsoon) to 87.75 ± 0.03% (monsoon) (Fig 4.4.2) (Table 4.4.3).

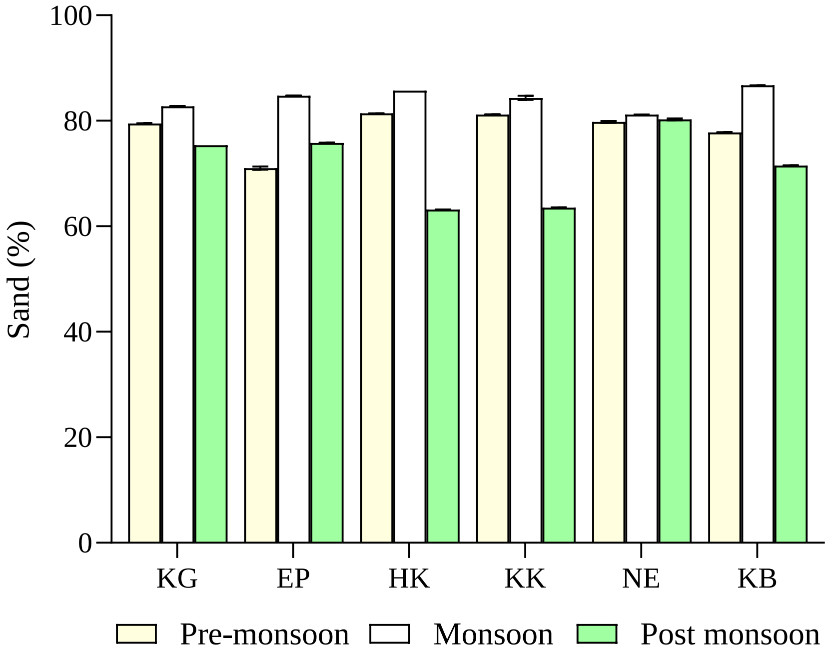


Fig 4.4.1: Sand content in selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the sand content at the top layer ranged from 63.56 ± 0.04% (post-monsoon) to 84.34 ± 0.40% (monsoon) (Fig 4.4.4) (Table 4.4.7). At the subsurface layer, the sand content ranged from 67.86 ± 0.05% (post-monsoon) to 76.79 ± 0.54% (monsoon) (Fig 4.4.2) (Table 4.4.4).

At site NE, the sand content at the top layer ranged from 79.77 ± 0.18% (pre-monsoon and monsoon) to 80.27 ± 0.19% (post-monsoon) (Fig 4.4.1) (Table 4.4.5).

At the subsurface layer, the sand content ranged from 78.45 ± 0.07% (post-monsoon) to 86.09 ± 0.12% (monsoon) (Fig 4.4.2) (Table 4.4.5).

At site KB, the sand content at the top layer ranged from 71.50 ± 0.09% (post-monsoon) to 86.71 ± 0.04% (monsoon) (Fig 4.4.1) (Table 4.4.6). At the subsurface layer, the sand content ranged from 72.21 ± 0.04% (post-monsoon) to 90.86 ± 0.14% (monsoon) (Fig 4.4.2) (Table 4.4.6).

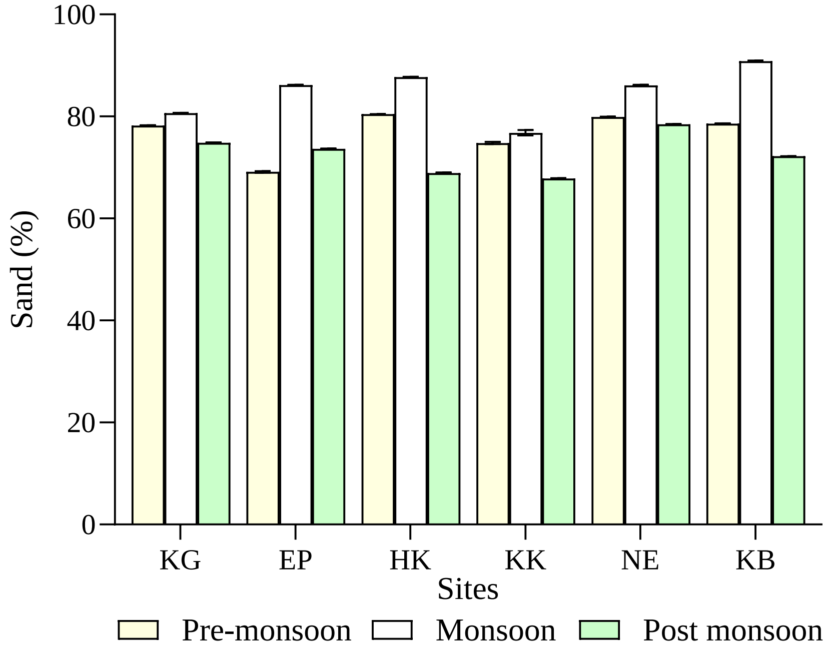


Fig 4.2.2: Sand content in selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.1.2. Silt

In Churachandpur at site KG, the silt content at the top layer ranged from 4.8 ± 0.05% (post-monsoon) to 12.28 ± 0.03% (pre-monsoon) (Fig 4.4.3) (Table 4.4.1). At the subsurface layer, the silt content ranged from 4.82 ± 0.06% (monsoon) to 12.54 ± 0.02% (pre-monsoon) (Fig 4.4.3) (Table 4.4.1).

At site EP, the silt content at the top layer ranged from 4.65 ± 0.04% (post-monsoon) to 26.66 ± 0.29% (pre-monsoon) (Fig 4.4.3) (Table 4.4.2). At the subsurface layer, the silt content ranged from 2.33 ± 0.02% (monsoon) to 28.4 ± 0.17% (pre-monsoon) (Fig 4.4.4) (Table 4.4.2).

At site HK, the silt content at the top layer ranged from 5.92 ± 0.06% (monsoon) to 31.32 ± 0.29% (post-monsoon) (Fig 4.4.4) (Table 4.4.3). At the subsurface layer, the silt content ranged from 4.64 ± 0.05% (monsoon) to 21.85 ± 0.11% (post-monsoon) (Fig 4.4.4) (Table 4.4.3).

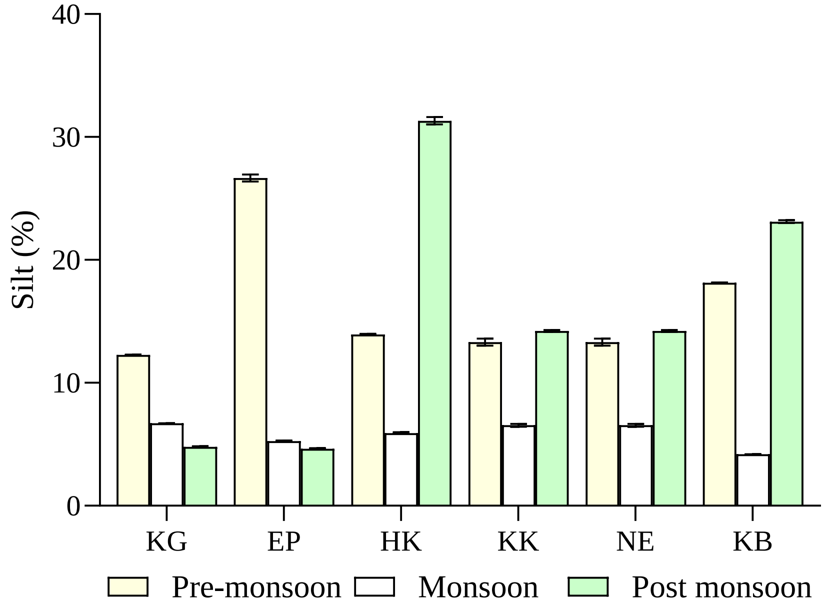


Fig 4.4.3: Silt content in selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the silt content at the top layer ranged from 12.22 ± 0.49% (monsoon) to 25.94 ± 0.12% (post-monsoon) (Fig 4.4.3) (Table 4.4.4). At the subsurface layer, the silt content ranged from 9.06 ± 0.14% (monsoon) to 21.59 ± 0.18% (post-monsoon) (Fig 4.4.4) (Table 4.4.4).

At site NE, the silt content at the top layer ranged from 6.55 ± 0.12% (monsoon) to 14.23 ± 0.08% (post-monsoon) (Fig 4.4.3) (Table 4.4.5). At the subsurface layer, the silt content ranged from 4.36 ± 0.08% (monsoon) to 17.87 ± 0.02% (post-monsoon) (Fig 4.4.4) (Table 4.4.5).

At site KB, the silt content at the top layer ranged from 4.19 ± 0.02% (monsoon) to 23.11 ± 0.11% (post-monsoon) (Fig 4.4.3) (Table 4.4.6). At the subsurface layer, the silt content ranged from 2.10 ± 0.07% (monsoon) to 21.17 ± 0.12% (post-monsoon) (Fig 4.4.4) (Table 4.4.6).

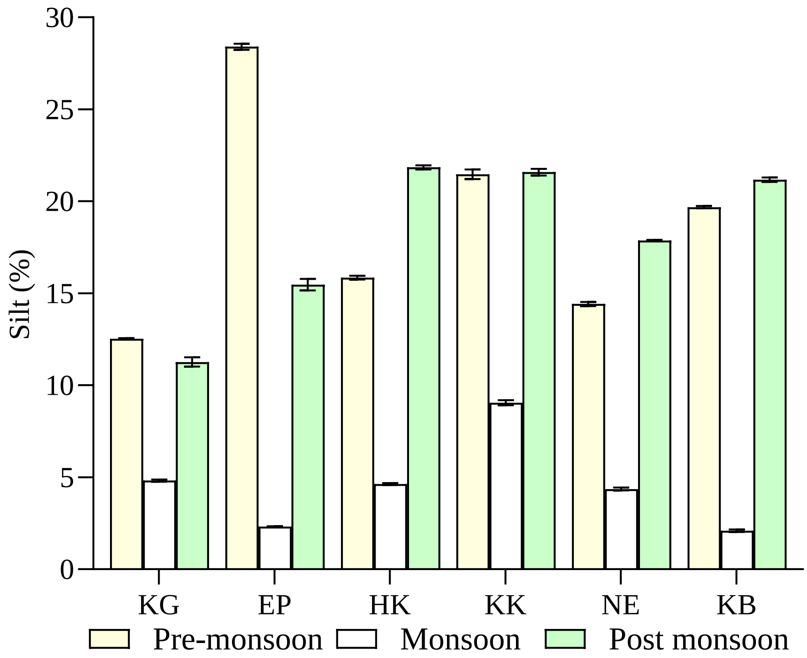


Fig 4.4.4: Silt content in selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.1.3. Clay

In Churachandpur at site KG, the clay content at the top layer ranged from 8.20 ± 0.04% (pre-monsoon) to 19.82 ± 0.06% (post-monsoon) (Fig 4.4.5) (Table 4.4.1). At the subsurface layer, the clay content ranged from 9.23 ± 0.02% (pre-monsoon) to 14.5 ± 0.06% (monsoon) (Fig 4.4.5) (Table 4.4.1).

At site EP, the clay content at the top layer ranged from 2.28 ± 0.08% (pre-monsoon) to 19.54 ± 0.09% (post-monsoon) (Fig 4.4.5) (Table 4.4.2). At the subsurface layer, the clay content ranged from 2.45 ± 0.06% (pre-monsoon) to 11.5 ± 0.05% (monsoon) (Fig 4.4.6) (Table 4.4.2).

At site HK, the clay content at the top layer ranged from 4.64 ± 0.07% (pre-monsoon) to 8.37 ± 0.07% (monsoon) (Fig 4.4.5) (Table 4.4.3). At the subsurface layer, the clay content ranged from 3.7 ± 0.12% (pre-monsoon) to 9.26 ± 0.06% (post-monsoon) (Fig 4.4.6) (Table 4.4.3).

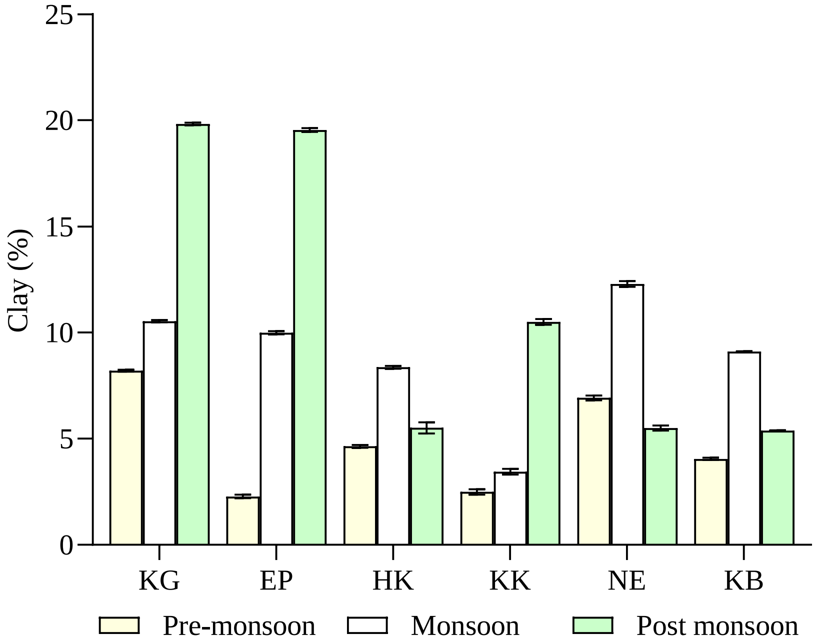


Fig 4.4.5: Clay content in selected jhum field of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the clay content at the top layer ranged from 2.49 ± 0.12% (pre-monsoon) to 10.5 ± 0.14% (post-monsoon) (Fig 4.4.5) (Table 4.4.4). At the subsurface layer, the clay content ranged from 3.75 ± 0.06% (pre-monsoon) to 14.19 ± 0.19% (monsoon) (Fig 4.4.6) (Table 4.4.4).

At site NE, the clay content at the top layer ranged from 5.5 ± 0.12% (post-monsoon) to 12.29 ± 0.14% (monsoon) (Fig 4.4.5) (Table 4.4.5). At the subsurface layer, the clay content ranged from 3.68 ± 0.06% (post-monsoon) to 9.55 ± 0.06% (monsoon) (Fig 4.4.6) (Table 4.4.5).

At site KB, the clay content at the top layer ranged from 4.05 ± 0.05% (pre-monsoon) to 9.10 ± 0.03% (monsoon) (Fig 4.4.5) (Table 4.4.6). At the subsurface layer, the clay content ranged from 1.73 ± 0.03% (pre-monsoon) to 7.04 ± 0.07% (monsoon) (Fig 4.4.6) (Table 4.4.6).

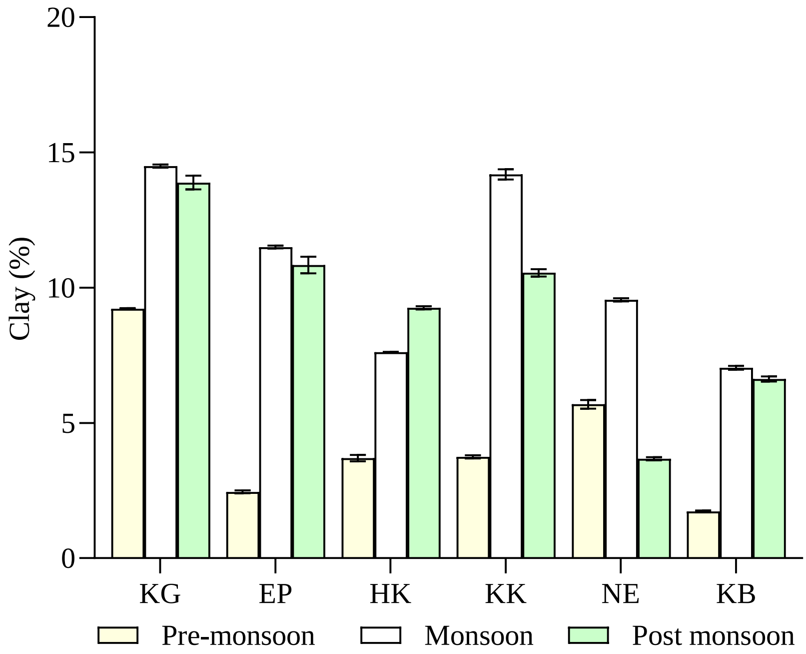


Fig 4.4.6: Clay content in selected jhum field of Churachandpur and Champhai (15-30 cm)

4.4.1.4. Texture

In Churachandpur at site KG, the soil texture at the top layer ranged from loamy sand (pre-monsoon and monsoon) to sandy loam (post-monsoon) (Table 4.4.1). At the subsurface layer, the soil texture remained sandy loam throughout all seasons (Table 4.4.1).

At site EP, the soil texture at the top layer ranged from loamy sand (monsoon) to sandy loam (pre-monsoon and post-monsoon) (Table 4.4.2). At the subsurface layer, the soil texture ranged from loamy sand (monsoon) to sandy loam (pre-monsoon and post-monsoon) (Table 4.4.2).

At site HK, the soil texture at the top layer ranged from loamy sand (pre-monsoon and monsoon) to sandy loam (post-monsoon) (Table 4.4.3). At the subsurface layer, the soil texture ranged from loamy sand (pre-monsoon and monsoon) to sandy loam (post-monsoon) (Table 4.4.3).

In Champhai at site KK, the soil texture at the top layer ranged from loamy sand (pre-monsoon and monsoon) to sandy loam (post-monsoon) (Table 4.4.4). At the subsurface layer, the soil texture ranged from loamy sand (pre-monsoon) to sandy loam (monsoon and post-monsoon) (Table 4.4.4).

At site NE, the soil texture at the top layer ranged from loamy sand (pre-monsoon and post-monsoon) to sandy loam (monsoon) (Table 4.4.5). At the subsurface layer, the soil texture remained loamy sand throughout all seasons (Table 4.4.5).

At site KB, the soil texture at the top layer ranged from loamy sand (pre-monsoon and monsoon) to sandy loam (post-monsoon) (Table 4.4.6). At the subsurface layer, the soil texture ranged from loamy sand (pre-monsoon) to sandy loam (monsoon and post-monsoon) (Table 4.4.6).

4.4.1.5. Soil Moisture Content (SMC)

In Churachandpur at site KG, the SMC at the top layer ranged from 17.8 ± 0.23% (post-monsoon) to 23.01 ± 0.25% (monsoon) (Fig 4.4.7) (Table 4.4.1). At the subsurface layer, the SMC ranged from 16.45 ± 0.15% (pre-monsoon) to 19.41 ± 0.15% (monsoon) (Fig 4.4.7) (Table 4.4.1).

At site EP, the SMC at the top layer ranged from 20.57 ± 0.42% (post-monsoon) to 24.62 ± 0.33% (monsoon) (Fig 4.4.7) (Table 4.4.2). At the subsurface layer, the SMC ranged from 18.84 ± 0.84% (post-monsoon) to 21.43 ± 0.66% (monsoon) (Fig 4.4.8) (Table 4.4.2).

At site HK, the SMC at the top layer ranged from 21.52 ± 0.36% (post-monsoon) to 24.04 ± 0.71% (monsoon) (Fig 4.4.8) (Table 4.4.3). At the subsurface layer, the SMC ranged from 23.45 ± 0.54% (pre-monsoon) to 25.4 ± 0.37% (monsoon) (Fig 4.4.8) (Table 4.4.3).

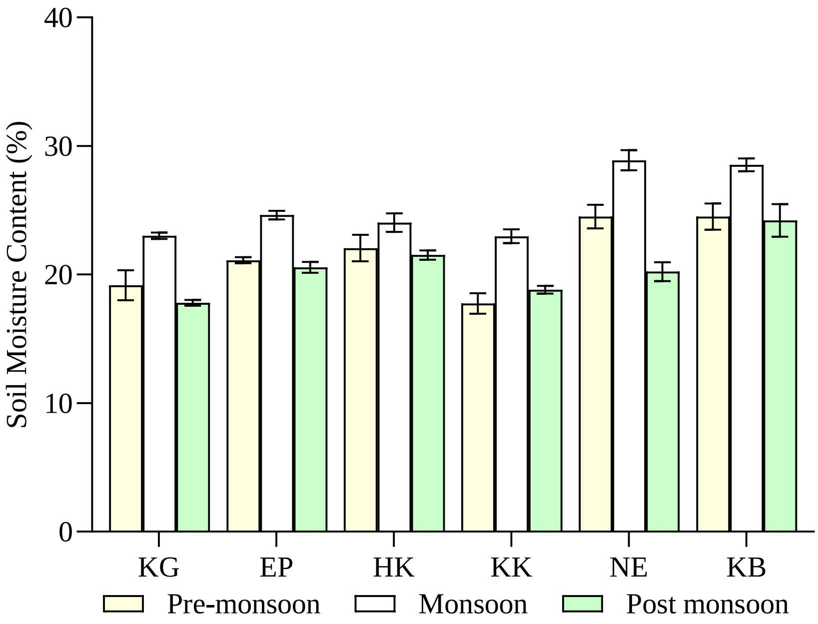


Fig 4.4.7: Soil moisture content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the SMC at the top layer ranged from 17.75 ± 0.80% (pre-monsoon) to 22.97 ± 0.54% (monsoon) (Fig 4.4.7) (Table 4.4.4). At the subsurface layer, the SMC ranged from 15.15 ± 0.83% (pre-monsoon) to 20.07 ± 0.35% (monsoon) (Fig 4.4.8) (Table 4.4.4).

At site NE, the SMC at the top layer ranged from 20.23 ± 0.73% (post-monsoon) to 28.89 ± 0.78% (monsoon) (Fig 4.4.7) (Table 4.4.5). At the subsurface layer, the SMC ranged from 18.88 ± 0.05% (post-monsoon) to 23.08 ± 0.66% (monsoon) (Fig 4.4.8) (Table 4.4.5).

At site KB, the SMC at the top layer ranged from 24.21 ± 1.27% (post-monsoon) to 28.54 ± 0.50% (monsoon) (Fig 4.4.7) (Table 4.4.6). At the subsurface layer, the SMC ranged from 17.90 ± 0.55% (post-monsoon) to 20.68 ± 0.33% (monsoon) (Fig 4.4.8) (Table 4.4.6).

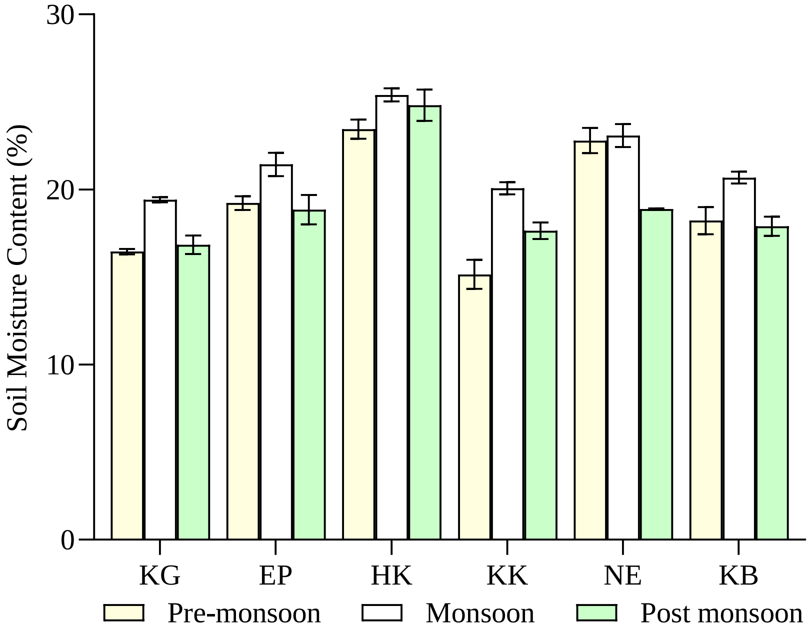


Fig 4.4.8: Soil moisture content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.1.6. Water Holding Capacity (WHC)

In Churachandpur at site KG, the WHC at the top layer ranged from 35.69 ± 0.09% (pre-monsoon) to 43.18 ± 0.12% (monsoon) (Fig 4.4.9) (Table 4.4.1). At the subsurface layer, the WHC ranged from 33.54 ± 0.04% (pre-monsoon) to 40.17 ± 0.29% (monsoon) (Fig 4.4.9) (Table 4.4.1).

At site EP, the WHC at the top layer ranged from 36.39 ± 0.01% (pre-monsoon) to 40.31 ± 0.25% (monsoon) (Fig 4.4.9) (Table 4.4.2). At the subsurface layer, the WHC ranged from 32.33 ± 0.10% (pre-monsoon) to 36.88 ± 0.04% (post-monsoon) (Fig 4.4.10) (Table 4.4.2).

At site HK, the WHC at the top layer ranged from 39.16 ± 0.02% (pre-monsoon) to 43.58 ± 0.17% (post-monsoon) (Fig 4.4.10) (Table 4.4.3). At the subsurface layer, the WHC ranged from 33.77 ± 0.05% (pre-monsoon) to 40.59 ± 0.12% (post-monsoon) (Fig 4.4.10) (Table 4.4.3).

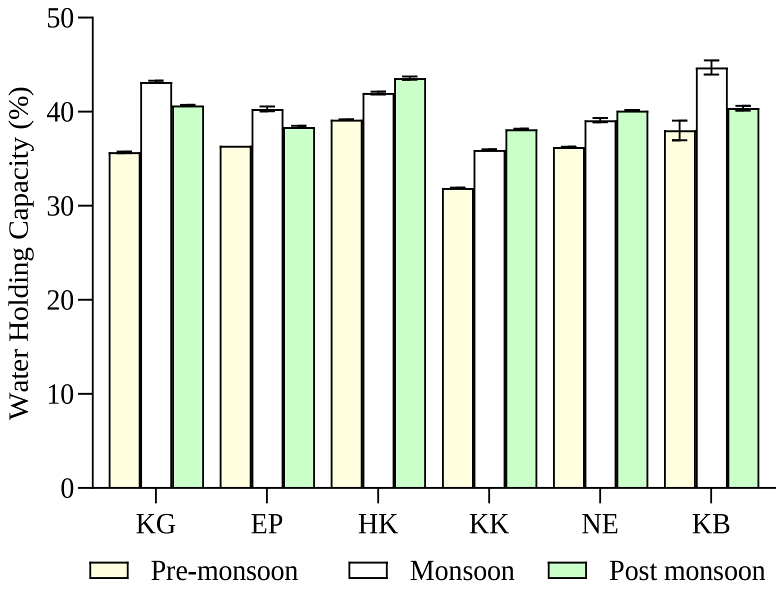


Fig 4.4.9: Water holding capacity of selected jhum fields at Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the WHC at the top layer ranged from 31.91% (pre-monsoon) to 38.13 ± 0.06% (post-monsoon) (Fig 4.4.9) (Table 4.4.4). At the subsurface layer, the WHC ranged from 30.28 ± 0.03% (pre-monsoon) to 37.48 ± 0.03% (post-monsoon) (Fig 4.4.10) (Table 4.4.4).

At site NE, the WHC at the top layer ranged from 36.27 ± 0.01% (pre-monsoon) to 40.14 ± 0.04% (post-monsoon) (Fig 4.4.9) (Table 4.4.5). At the subsurface layer, the WHC ranged from 32.49 ± 0.03% (pre-monsoon) to 39.41 ± 0.06% (post-monsoon) (Fig 4.4.10) (Table 4.4.5).

At site KB, the WHC at the top layer ranged from 38.02 ± 1.04% (pre-monsoon) to 44.71 ± 0.75% (monsoon) (Fig 4.4.9) (Table 4.4.6). At the subsurface layer, the WHC ranged from 35.30 ± 0.99% (pre-monsoon) to 38.02 ± 0.10% (post-monsoon) (Fig 4.4.10) (Table 4.4.6).

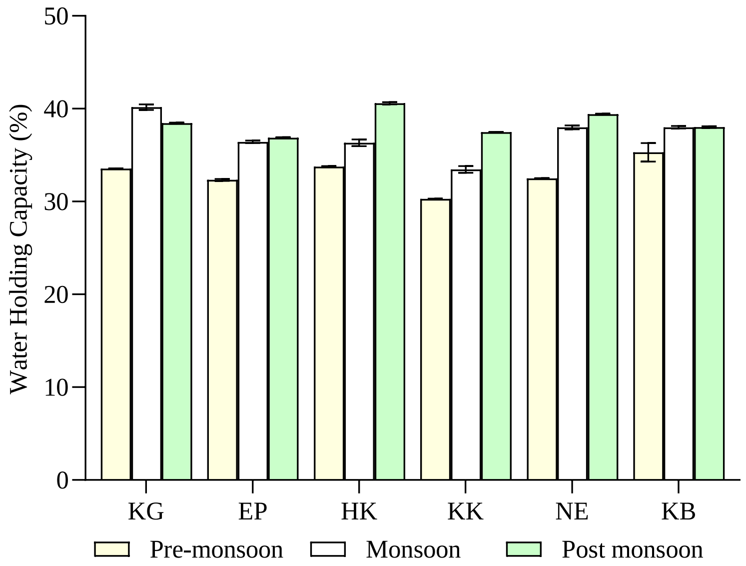


Fig 4.4.10: Water holding capacity of selected jhum fields at Churachandpur and Champhai (15-30 cm)

4.4.1.7. Bulk Density (BD)

In Churachandpur at site KG, the BD at the top layer ranged from 1.12 ± 0.01 (monsoon) to 1.28 ± 0.01 g/cm³ (pre-monsoon) (Fig 4.4.11) (Table 4.4.1). At the subsurface layer, the BD ranged from 1.16 ± 0.01 g/cm³ (pre-monsoon) to 1.29 ± 0.01 g/cm³ (monsoon) (Fig 4.4.12) (Table 4.4.1).

At site EP, the BD at the top layer ranged from 1.14 ± 0.01 (pre-monsoon) to 1.24 ± 0.10 g/cm³ (monsoon) (Fig 4.4.11) (Table 4.4.2). At the subsurface layer, the BD ranged from 1.25 ± 0.01 (monsoon) to 1.33 ± 0.01 g/cm³ (post-monsoon) (Fig 4.4.12) (Table 4.4.2).

At site HK, the BD at the top layer ranged from 0.93 ± 0.01 (pre-monsoon) to 1.12 ± 0.02 g/cm³ (monsoon) (Fig 4.4.11) (Table 4.4.3). At the subsurface layer, the BD ranged from 1.18 ± 0.01 (pre-monsoon) to 1.2 ± 0.01 g/cm³ (monsoon) (Fig 4.4.12) (Table 4.4.3).

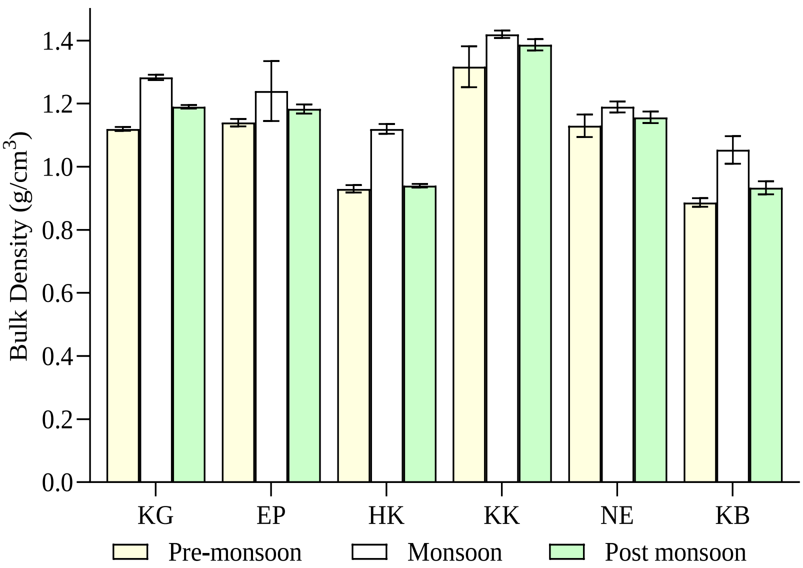


Fig 4.4.11: Bulk density of selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the BD at the top layer ranged from 1.32 ± 0.06 (pre-monsoon) to 1.42 ± 0.01 g/cm³ (monsoon) (Fig 4.4.11) (Table 4.4.4). At the subsurface layer, the BD ranged from 1.41 ± 0.06 (pre-monsoon) to 1.45 ± 0.02 g/cm³ (monsoon) (Fig 4.4.12) (Table 4.4.4).

At site NE, the BD at the top layer ranged from 1.13 ± 0.04 (pre-monsoon) to 1.19 ± 0.02 g/cm³ (monsoon) (Fig 4.4.11) (Table 4.4.5). At the subsurface layer, the BD ranged from 1.15 ± 0.03 (pre-monsoon) to 1.21 ± 0.02 g/cm³ (monsoon) (Fig 4.4.12) (Table 4.4.5).

At site KB, the BD at the top layer ranged from 0.89 ± 0.01 (pre-monsoon) to 1.05 ± 0.04 g/cm³ (monsoon) (Fig 4.4.11) (Table 4.4.6). At the subsurface layer, the BD ranged from 0.98 ± 0.02 (pre-monsoon) to 1.15 ± 0.01 g/cm³ (monsoon) (Fig 4.4.12) (Table 4.4.6).

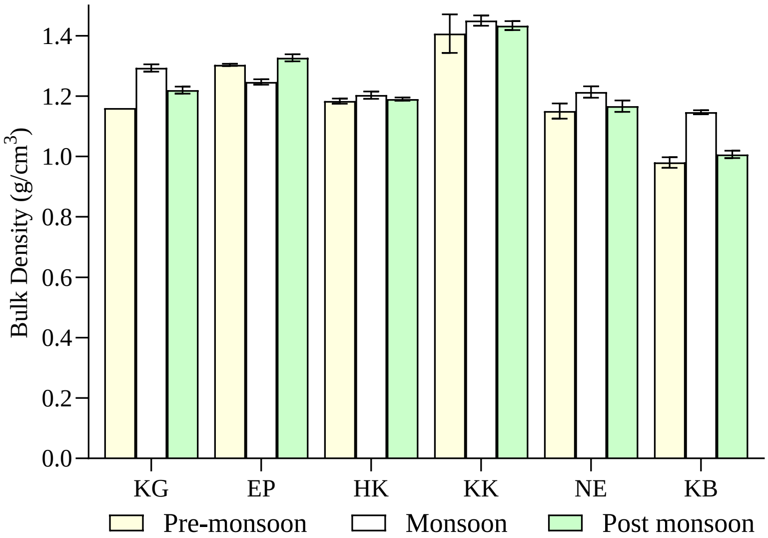


Fig 4.4.12: Bulk density of selected jhum fields of Churachandpur and Champhai (15-30 cm)

Table 4.4.1: Physical properties of soil at site KG (mean ±SEM)

Depth	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (g/cm^3)
0-15	**Pre-monsoon**	79.51 ±0.02	12.28 ±0.03	8.20 ±.04	Loamy sand	19.17 ±1.18	35.69 ±0.09	1.28 ±0.01
	Monsoon	82.75 ±0.03	6.71 ±0.02	10.54 ±0.05	Loamy sand	23.01 ±0.25	43.18 ±0.12	1.12 ±0.01
	Post monsoon	75.38 ±0.03	4.8 ±0.05	19.82 ±0.06	Sandy loam	17.8 ±0.23	40.67 ±0.07	1.19 ±0.01
15-30	**Pre-monsoon**	78.24 ±0.02	12.54 ±0.02	9.23 ±0.02	Sandy loam	16.45 ±0.15	33.54 ±0.04	1.16 ±0.01
	Monsoon	80.68 ±0.01	4.82 ±0.06	14.5 ±0.06	Sandy loam	19.41 ±0.15	40.17 ±0.29	1.29 ±0.01
	Post monsoon	74.85 ±0.03	11.27 ±0.25	13.89 ±0.25	Sandy loam	16.84 ±0.53	38.44 ±0.06	1.22 ±0.01

Table 4.4.2: Physical properties of soil at site EP (mean ±SEM)

Depth	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (g/cm^3)
0-15	**Pre-monsoon**	71.06 ±0.30	26.66 ±0.29	2.28 ±0.08	Sandy loam	21.11 ±0.23	36.39 ±0.01	1.14 ±0.01
	Monsoon	84.74 ±0.03	5.27 ±0.04	9.99 ±0.07	Loamy sand	24.62 ±0.33	40.31 ±0.25	1.24 ±0.10
	Post monsoon	75.82 ±0.05	4.65 ±0.04	19.54 ±0.09	Sandy loam	20.57 ±0.42	38.38 ±0.12	1.18 ±0.01
15-30	**Pre-monsoon**	69.15 ±0.16	28.4 ±0.17	2.45 ±0.06	Sandy loam	19.23 ±0.39	32.33 ±0.10	1.30 ±0.01
	Monsoon	86.17 ±0.04	2.33 ±0.02	11.5 ±0.05	Loamy sand	21.43 ±0.66	36.43 ±0.13	1.25 ±0.01
	Post monsoon	73.69 ±0.01	15.48 ±0.31	10.84 ±0.31	Sandy loam	18.84 ±0.84	36.88 ±0.04	1.33 ±0.01

Table 4.4.3: Physical properties of soil at site HK (mean ±SEM)

Depth	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (g/cm3)
0-15	**Pre-monsoon**	81.41 ±0.04	13.95 ±0.04	4.64 ±0.07	Loamy sand	22.06 ±1.02	39.16 ±0.02	0.93 ±0.01
	Monsoon	85.71 ±0.01	5.92 ±0.06	8.37 ±0.07	Loamy sand	24.04 ±0.71	41.99 ±0.14	1.12 ±0.02
	Post monsoon	63.17 ±0.03	31.32 ±0.29	5.51 ±0.26	Sandy loam	21.52 ±0.36	43.58 ±0.17	0.94 ±0.01
15-30	**Pre-monsoon**	80.45 ±0.05	15.85 ±0.11	3.7 ±0.12	Loamy sand	23.45 ±0.54	33.77 ±0.05	1.18 ±0.01
	Monsoon	87.75 ±0.03	4.64 ±0.05	7.61 ±0.02	Loamy sand	25.4 ±0.37	36.33 ±0.37	1.2 ±0.01
	Post monsoon	68.89 ±0.11	21.85 ±0.11	9.26 ±0.06	Sandy loam	24.81 ±0.89	40.59 ±0.12	1.19 ±0.01

Table 4.4.4: Physical properties of soil at site KK (mean ±SEM)

Depths	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (g/cm3)
0-15	**Pre-monsoon**	81.18 ±0.06	16.33 ±0.06	2.49 ±0.12	Loamy sand	17.75 ±0.80	31.91	1.32 ±0.06
15-30		74.79 ±0.22	21.47 ±0.26	3.75 ±0.06	Loamy sand	15.15 ±0.83	30.28 ±0.03	1.41 ±0.06
0-15	**Monsoon**	84.34 ±0.40	12.22 ±0.49	3.44 ±0.14	Loamy sand	22.97 ±0.54	35.93 ±0.06	1.42 ±0.01
15-30		76.79 ±0.54	9.06 ±0.14	14.19 ±0.19	Sandy loam	20.07 ±0.35	33.45 ±0.37	1.45 ±0.02
0-15	**Post monsoon**	63.56 ±0.04	25.94 ±0.12	10.5 ±0.14	Sandy loam	18.81 ±0.30	38.13 ±0.06	1.39 ±0.02
15-30		67.86 ±0.05	21.59 ±0.18	10.55 ±0.14	Sandy loam	17.64 ±0.47	37.48 ±0.03	1.43 ±0.01

Table 4.4.5: Physical properties of soil at NE (mean ±SEM)

Depths	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (g/cm3)
0-15	**Pre-monsoon**	79.77 ±0.18	13.31 ±0.29	6.92 ±0.11	Loamy sand	24.51 ±0.91	36.27 ±0.01	1.13 ±0.04
	Monsoon	81.16 ±0.02	6.55 ±0.12	12.29 ±0.14	Sandy loam	28.89 ±0.78	39.11 ±0.23	1.19 ±0.02
	Post monsoon	80.27 ±0.19	14.23 ±0.08	5.5 ±0.12	Loamy sand	20.23 ±0.73	40.14 ±0.04	1.16 ±0.02
15-30	**Pre-monsoon**	79.89 ±0.10	14.42 ±0.11	5.69 ±0.16	Loamy sand	22.79 ±0.72	32.49 ±0.03	1.15 ±0.03
	Monsoon	86.09 ±0.12	4.36 ±0.08	9.55 ±0.06	Loamy sand	23.08 ±0.66	37.99 ±0.20	1.21 ±0.02
	Post monsoon	78.45 ±0.07	17.87 ±0.02	3.68 ±0.06	Loamy sand	18.88 ±0.05	39.41 ±0.06	1.17 ±0.02

Table 4.4.6: Physical properties of soil at KB (mean ±SEM)

Depth	Seasons	Sand (%)	Silt (%)	Clay (%)	Texture	SMC (%)	WHC (%)	BD (%)
0-15	**Pre-monsoon**	77.82 ±0.06	18.13 ±0.03	4.05 ±0.05	Loamy sand	24.51 ±1.03	38.02 ±1.04	0.89 ±0.01
	Monsoon	86.71 ±0.04	4.19 ±0.02	9.10 ±0.03	Loamy sand	28.54 ±0.50	44.71 ±0.75	1.05 ±0.04
	Post monsoon	71.50 ±0.09	23.11 ±0.11	5.38 ±0.02	Sandy loam	24.21 ±1.27	40.38 ±0.27	0.93 ±0.02
15-30	**Pre-monsoon**	78.59 ±0.05	19.68 ±0.06	1.73 ±0.03	Loamy sand	18.22 ±0.78	35.30 ±0.99	0.98 ±0.02
	Monsoon	90.86 ±0.14	2.10 ±0.07	7.04 ±0.07	Sandy loam	20.68 ±0.33	38 ±0.13	1.15 ±0.01
	Post monsoon	72.21 ±0.04	21.17 ±0.12	6.62 ±0.10	Sandy loam	17.90 ±0.55	38.02 ±0.10	1.01 ±0.01

4.4.2. Chemical properties of soil

4.4.2.1. pH

In Churachandpur at site KG, the pH at the top layer ranged from 5.62 ± 0.05 (monsoon) to 6.48 ± 0.03 (pre-monsoon) (Fig 4.4.13) (Table 4.4.7). At the subsurface layer, the pH ranged from 5.55 ± 0.03 (monsoon) to 6.35 ± 0.06 (pre-monsoon) (Fig 4.4.14) (Table 4.4.7).

At site EP, the pH at the top layer ranged from 5.62 ± 0.05 (monsoon) to 5.9 ± 0.01 (pre-monsoon) (Fig 4.4.13) (Table 4.4.8). At the subsurface layer, the pH ranged from 5.61 ± 0.02 (monsoon) to 5.7 ± 0.01 (pre-monsoon) (Fig 4.4.8) (Table 4.4.4).

At site HK, the pH at the top layer ranged from 5.66 ± 0.03 (monsoon) to 6.41 ± 0.04 (pre-monsoon) (Fig 4.4.13) (Table 4.4.9). At the subsurface layer, the pH ranged from 5.57 ± 0.57 (monsoon) to 6.26 ± 0.18 (pre-monsoon) (Fig 4.4.14) (Table 4.4.9).

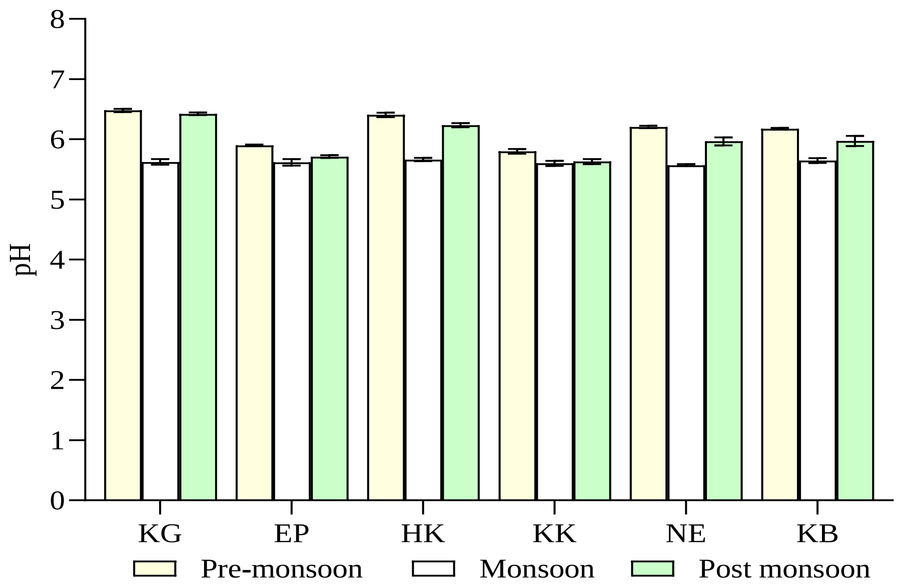


Fig 4.4.13: Soil pH of selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the pH at the top layer ranged from 5.6 ± 0.04 (monsoon) to 5.8 ± 0.04 (pre-monsoon) (Fig 4.4.10) (Table 4.4.8). At the subsurface layer, the pH ranged from 5.54 ± 0.03 (monsoon) to 5.76 ± 0.04 (pre-monsoon) (Fig 4.4.14) (Table 4.4.10).

At site NE, the pH at the top layer ranged from 5.57 ± 0.02 (monsoon) to 6.21 ± 0.02 (pre-monsoon) (Fig 4.4.13) (Table 4.4.11). At the subsurface layer, the pH ranged from 5.48 ± 0.03 (monsoon) to 5.85 ± 0.03 (pre-monsoon) (Fig 4.4.14) (Table 4.4.11).

At site KB, the pH at the top layer ranged from 5.65 ± 0.04 (monsoon) to 6.18 ± 0.01 (pre-monsoon) (Fig 4.4.13) (Table 4.4.11). At the subsurface layer, the pH ranged from 5.59 ± 0.02 (post-monsoon) to 5.93 ± 0.08 (pre-monsoon) (Fig 4.4.14) (Table 4.4.11).

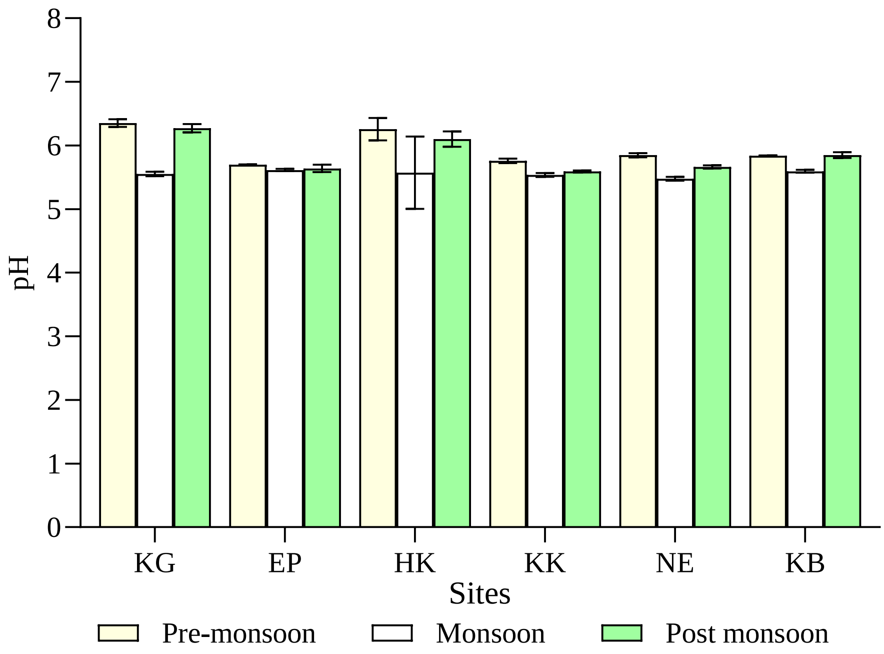


Fig 4.4.14: Soil pH of selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.2. Electrical Conductivity (EC)

In Churachandpur at site KG, the EC at the top layer ranged from 0.18 ± 0.01 (monsoon) to 0.26 ± 0.01 dSm^{-1} (post-monsoon) (Fig 4.4.15) (Table 4.4.7). At the subsurface layer, the EC ranged from 0.12 ± 0.02 (monsoon) to 0.19 ± 0.02 dSm^{-1} (pre-monsoon) (Fig 4.4.16) (Table 4.4.7).

At site EP, the EC at the top layer ranged from 0.16 ± 0.02 (monsoon) to 0.23 ± 0.02 dSm⁻¹ (post-monsoon) (Fig 4.4.15) (Table 4.4.8). At the subsurface layer, the EC ranged from 0.11 ± 0.01 (monsoon) to 0.17 ± 0.02 dSm⁻¹ (pre-monsoon) (Fig 4.4.16) (Table 4.4.8).

At site HK, the EC at the top layer ranged from 0.18 ± 0.01 (monsoon) to 0.23 ± 0.02 dSm⁻¹ (post-monsoon) (Fig 4.4.15) (Table 4.4.9). At the subsurface layer, the EC ranged from 0.12 ± 0.02 (monsoon) to 0.15 ± 0.02 dSm⁻¹ (post-monsoon) (Fig 4.4.16) (Table 4.4.9).

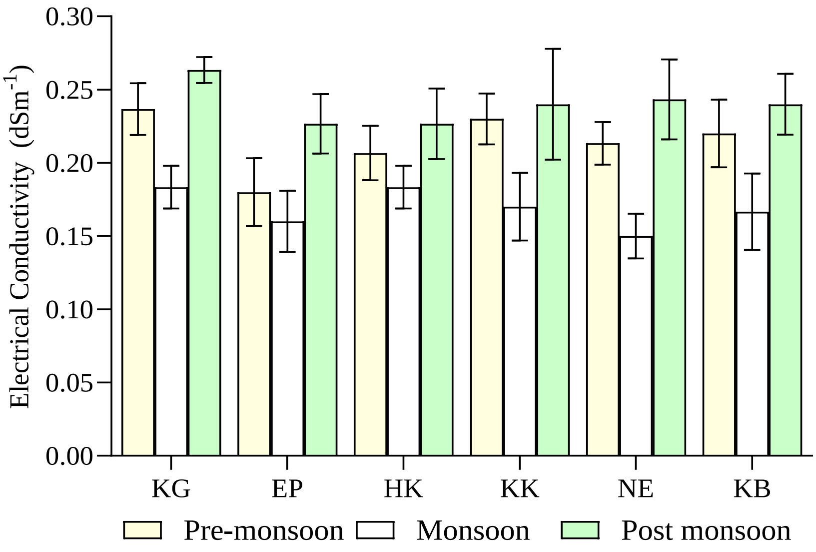


Fig 4.4.15: Electrical conductivity at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the EC at the top layer ranged from 0.17 ± 0.02 (monsoon) to 0.24 ± 0.04 dSm⁻¹ (post-monsoon) (Fig 4.4.15) (Table 4.4.10). At the subsurface layer, the EC ranged from 0.11 ± 0.02 (monsoon) to 0.18 ± 0.03 dSm⁻¹ (pre-monsoon) (Fig 4.4.16) (Table 4.4.10).

At site NE, the EC at the top layer ranged from 0.15 ± 0.02 (monsoon) to 0.24 ± 0.03 dSm⁻¹ (post-monsoon) (Fig 4.4.15) (Table 4.4.11). At the subsurface layer, the EC ranged from 0.12 ± 0.02 (monsoon) to 0.19 ± 0.02 dSm⁻¹ (pre-monsoon) (Fig 4.4.16) (Table 4.4.11).

At site KB, the EC at the top layer ranged from 0.17 ± 0.03 (monsoon) to 0.24 ± 0.02 dSm⁻¹ (post-monsoon) (Fig 4.4.15) (Table 4.4.12). At the subsurface layer, the EC ranged from 0.13 ± 0.02 (post-monsoon) to 0.21 ± 0.02 dSm⁻¹ (pre-monsoon) (Fig 4.4.16) (Table 4.4.12).

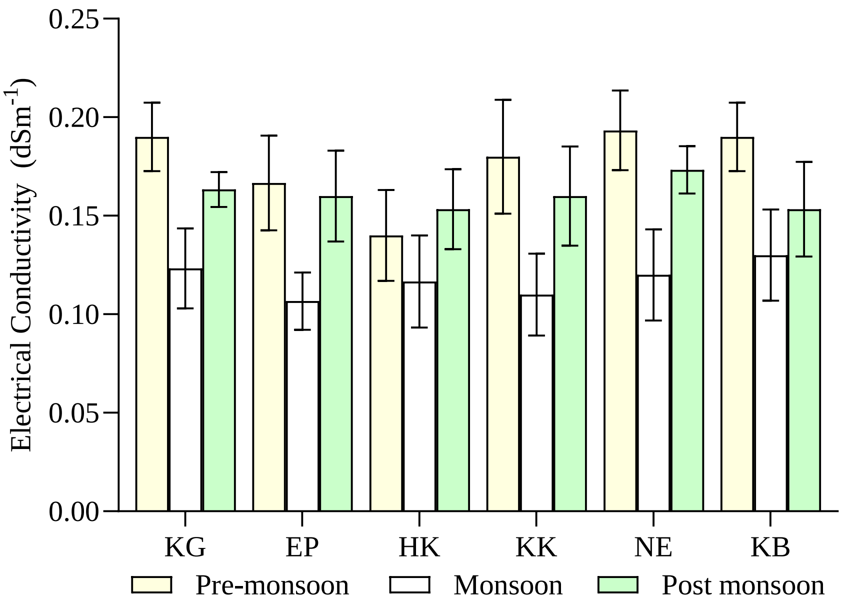


Fig 4.4.16: Electrical conductivity at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.3. Soil Organic Carbon (SOC)

In Churachandpur at site KG, the SOC at the top layer ranged from 2.26 ± 0.03 (monsoon) to 2.71 ± 0.04% (pre-monsoon) (Fig 4.4.17) (Table 4.4.7). At the subsurface layer, the SOC ranged from 1.8 ± 0.06 (monsoon) to 2.16 ± 0.03% (pre-monsoon) (Fig 4.4.18) (Table 4.4.7).

At site EP, the SOC at the top layer ranged from 1.78 ± 0.07 (monsoon) to 2.22 ± 0.08% (pre-monsoon) (Fig 4.4.17) (Table 4.4.8). At the subsurface layer, the SOC ranged from 1.5 ± 0.10 (monsoon) to 2.07 ± 0.07% (pre-monsoon) (Fig 4.4.18) (Table 4.4.8).

At site HK, the SOC at the top layer ranged from 2.67 ± 0.04 (monsoon) to 3.03 ± 0.13% (pre-monsoon) (Fig 4.4.17) (Table 4.4.9). At the subsurface layer, the

SOC ranged from 2.34 ± 0.02 (monsoon) to 3.53 ± 0.17% (post-monsoon) (Fig 4.4.18) (Table 4.4.9).

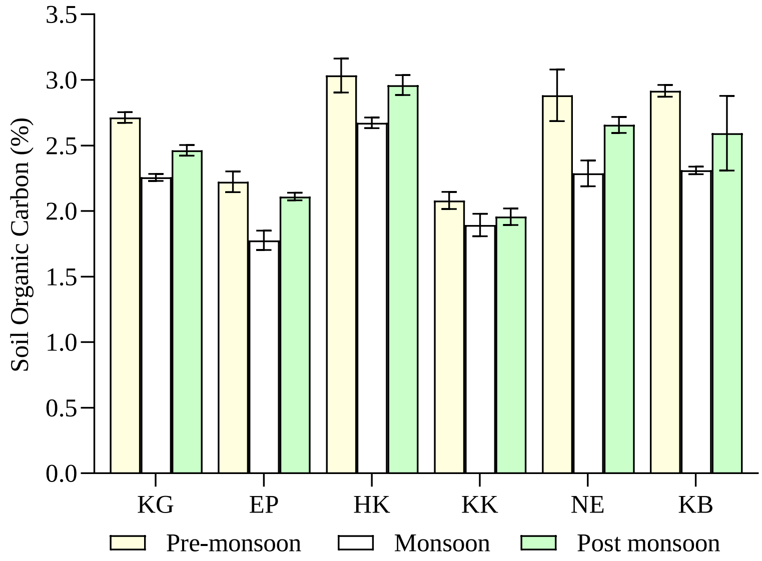


Fig 4.4.17: Soil organic carbon content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the SOC at the top layer ranged from 1.89 ± 0.09 (monsoon) to 2.08 ± 0.07% (pre-monsoon) (Fig 4.4.17) (Table 4.4.10). At the subsurface layer, the SOC ranged from 0.76 ± 0.10 (monsoon) to 0.98 ± 0.07% (pre-monsoon) (Fig 4.4.18) (Table 4.4.10).

At site NE, the SOC at the top layer ranged from 2.29 ± 0.10 (monsoon) to 2.88 ± 0.20% (pre-monsoon) (Fig 4.4.17) (Table 4.4.11). At the subsurface layer, the SOC ranged from 1.25 ± 0.03 (post-monsoon) to 2.12 ± 0.04% (pre-monsoon) (Fig 4.4.18) (Table 4.4.11).

At site KB, the SOC at the top layer ranged from 2.31 ± 0.03 (monsoon) to 2.92 ± 0.04% (pre-monsoon) (Fig 4.4.17) (Table 4.4.12). At the subsurface layer, the SOC ranged from 2.26 ± 0.26 (post-monsoon) to 2.66 ± 0.02% (monsoon) (Fig 4.4.18) (Table 4.4.12).

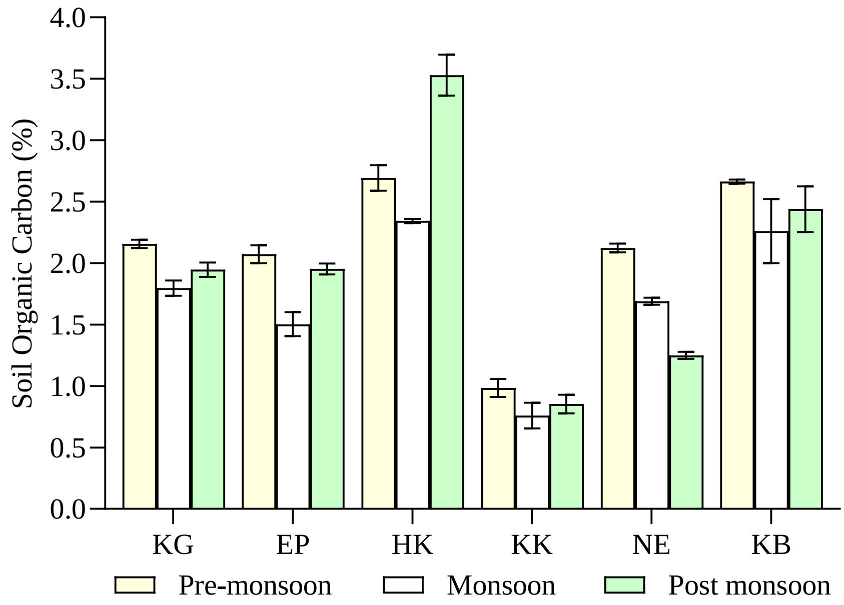


Fig 4.4.18: Soil organic carbon content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.4. Available Nitrogen

In Churachandpur at site KG, the Avail. N at the top layer ranged from 459.95 ± 27.66 (pre-monsoon) to 512.21 ± 10.45 kg/ha (monsoon) (Fig 4.4.19) (Table 4.4.7). At the subsurface layer, the Avail. N ranged from 271.79 ± 10.45 (post-monsoon) to 407.68 ± 18.11 kg/ha (pre-monsoon) (Fig 4.4.20) (Table 4.4.7).

At site EP, the Avail. N at the top layer ranged from 303.15 ± 27.66 (monsoon) to 428.59 ± 10.45 kg/ha (post-monsoon) (Fig 4.4.19) (Table 4.4.8). At the subsurface layer, the Avail. N ranged from 261.33 ± 10.45 (monsoon) to 386.77 ± 10.45 kg/ha (post-monsoon) (Fig 4.4.20) (Table 4.4.8).

At site HK, the Avail. N at the top layer ranged from 324.05 ± 10.45 (pre-monsoon) to 616.75 ± 10.45 kg/ha (post-monsoon) (Fig 4.4.19) (Table 4.4.9). At the subsurface layer, the Avail. N ranged from 219.52 ± 18.11 (pre-monsoon) to 533.12 ± 18.11 kg/ha (post-monsoon) (Fig 4.4.20) (Table 4.4.9).

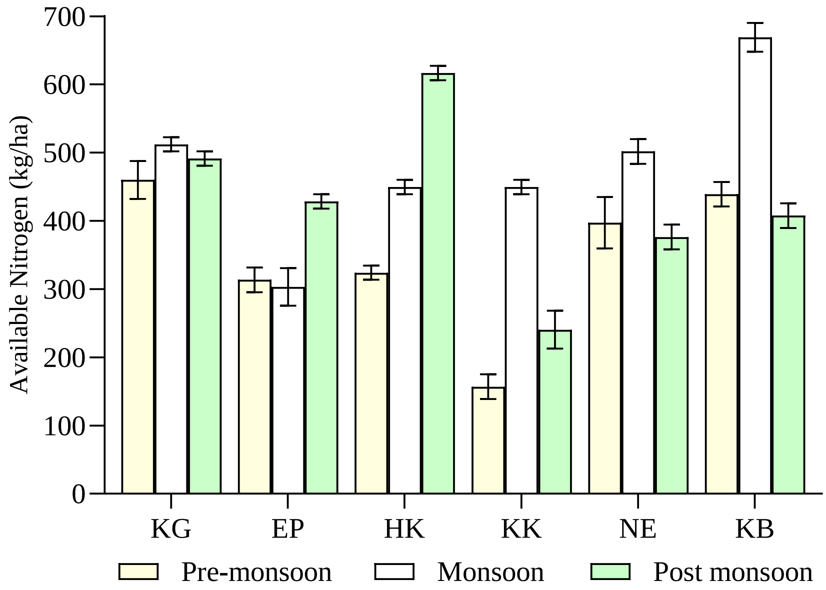


Fig 4.4.19: Available nitrogen content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Avail. N at the top layer ranged from 156.8 ± 18.11 (pre-monsoon) to 449.49 ± 10.45 kg/ha (monsoon) (Fig 4.4.19) (Table 4.4.10). At the subsurface layer, the Avail. N ranged from 135.89 ± 10.45 (pre-monsoon) to 321.51 ± 19.76 kg/ha (monsoon) (Fig 4.4.20) (Table 4.4.10).

At site NE, the Avail. N at the top layer ranged from 376.32 ± 18.11 (post-monsoon) to 501.76 ± 18.11 kg/ha (monsoon) (Fig 4.4.19) (Table 4.4.11). At the subsurface layer, the Avail. N ranged from 219.52 ± 36.21 (post-monsoon) to 428.59 ± 10.45 kg/ha (monsoon) (Fig 4.4.20) (Table 4.4.11).

At site KB, the Avail. N at the top layer ranged from 407.64 ± 18.14 (post-monsoon) to 669.01 ± 20.91 kg/ha (monsoon) (Fig 4.4.19) (Table 4.4.12). At the subsurface layer, the Avail. N ranged from 250.88 ± 18.11 (monsoon) to 637.65 ± 27.66 kg/ha (post-monsoon) (Fig 4.4.20) (Table 4.4.12).

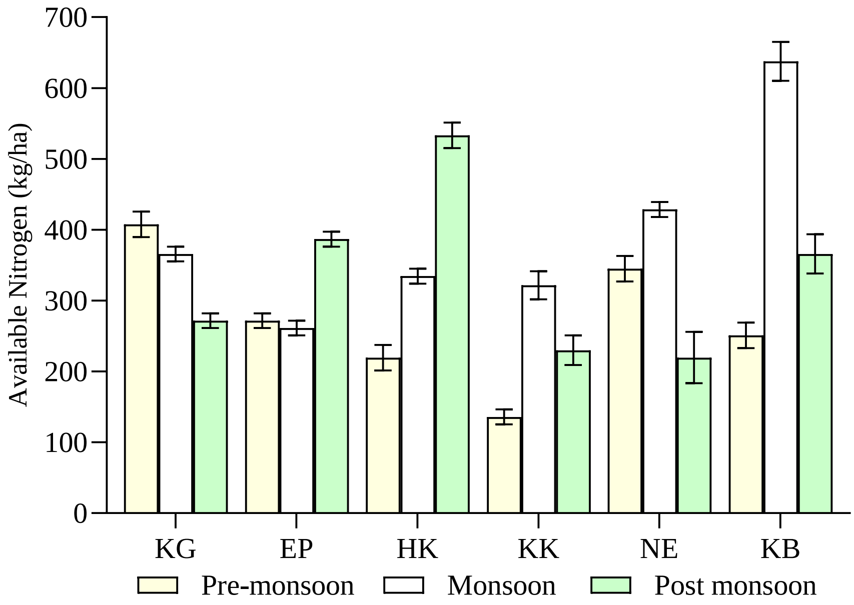


Fig 4.4.20: Available nitrogen content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.5. Available Phosphorus

In Churachandpur at site KG, the Avail. P at the top layer ranged from 27.21 ± 1.15 (pre-monsoon) to 35.36 ± 0.84 kg/ha (monsoon) (Fig 4.4.21) (Table 4.4.7). At the subsurface layer, the Avail. P ranged from 22.44 ± 0.69 (pre-monsoon) to 32.77 ± 0.94 kg/ha (monsoon) (Fig 4.4.22) (Table 4.4.7).

At site EP, the Avail. P at the top layer ranged from 21.66 ± 0.38 (pre-monsoon) to 31.19 ± 1 kg/ha (monsoon) (Fig 4.4.21) (Table 4.4.8). At the subsurface layer, the Avail. P ranged from 19.44 ± 1.26 (pre-monsoon) to 24.63 ± 0.91 kg/ha (monsoon) (Fig 4.4.22) (Table 4.4.8).

At site HK, the Avail. P at the top layer ranged from 29.05 ± 0.76 (pre-monsoon) to 38.1 ± 2.86 kg/ha (monsoon) (Fig 4.4.21) (Table 4.4.9). At the subsurface layer, the Avail. P ranged from 22.44 ± 0.50 (pre-monsoon) to 34.13 ± 0.73 kg/ha (monsoon) (Fig 4.4.22) (Table 4.4.9).

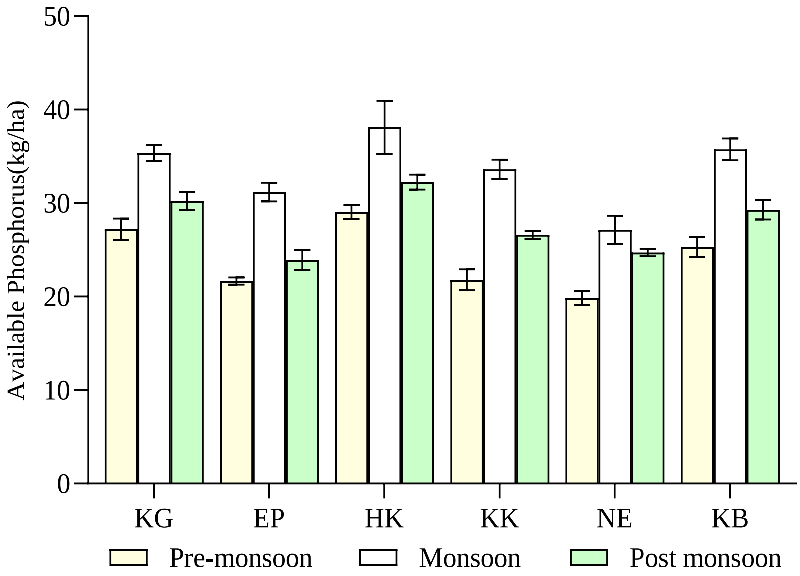


Fig 4.4.21: Available phosphorus content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Avail. P at the top layer ranged from 21.8 ± 1.11 kg/ha (pre-monsoon) to 33.61 ± 1.02 (monsoon) (Fig 4.4.21) (Table 4.4.10). At the subsurface layer, the Avail. P ranged from 19.77 ± 1.06 (pre-monsoon) to 25.46 ± 0.82 kg/ha (monsoon) (Fig 4.4.22) (Table 4.4.10).

At site NE, the Avail. P at the top layer ranged from 19.85 ± 0.76 (pre-monsoon) to 27.15 ± 1.51 kg/ha (monsoon) (Fig 4.4.21) (Table 4.4.11). At the subsurface layer, the Avail. P ranged from 18.1 ± 0.48 (pre-monsoon) to 25.02 ± 0.62 kg/ha (monsoon) (Fig 4.4.22) (Table 4.4.11).

At site KB, the Avail. P at the top layer ranged from 25.31 ± 1.07 (pre-monsoon) to 35.75 ± 1.16 kg/ha (monsoon) (Fig 4.4.21) (Table 4.4.12). At the subsurface layer, the Avail. P ranged from 23.47 ± 0.80 (monsoon) to 33.23 ± 0.20 kg/ha (post-monsoon) (Fig 4.4.22) (Table 4.4.12).

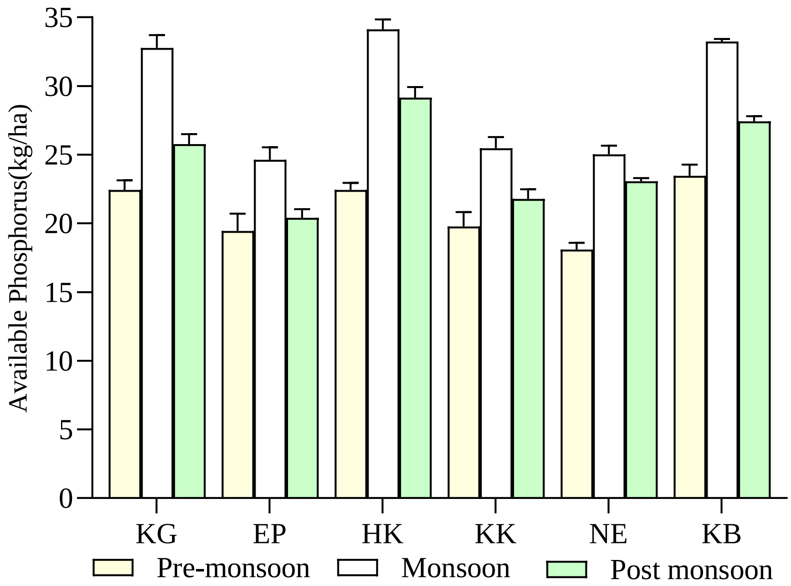


Fig 4.4.22: Available phosphorus content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.6. Available Potassium

In Churachandpur at site KG, the Avail. K at the top layer ranged from 168.47 ± 1.17 (pre-monsoon) to 212.94 ± 2.87 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.7). At the subsurface layer, the Avail. K ranged from 153.14 ± 1.10 (post-monsoon) to 166.87 ± 3.62 kg/ha (monsoon) (Fig 4.4.24) (Table 4.4.7).

At site EP, the Avail. K at the top layer ranged from 249.82 ± 1.58 (pre-monsoon) to 262.12 ± 2.26 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.8). At the subsurface layer, the Avail. K ranged from 242.74 ± 3.52 (pre-monsoon) to 257.2 ± 1.53 kg/ha (monsoon) (Fig 4.4.24) (Table 4.4.8).

At site HK, the Avail. K at the top layer ranged from 237.6 ± 1.82 (pre-monsoon) to 263.68 ± 1.76 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.9). At the subsurface layer, the Avail. K ranged from 231.4 ± 1.65 (pre-monsoon) to 245.62 ± 2.47 kg/ha (monsoon) (Fig 4.4.24) (Table 4.4.9).

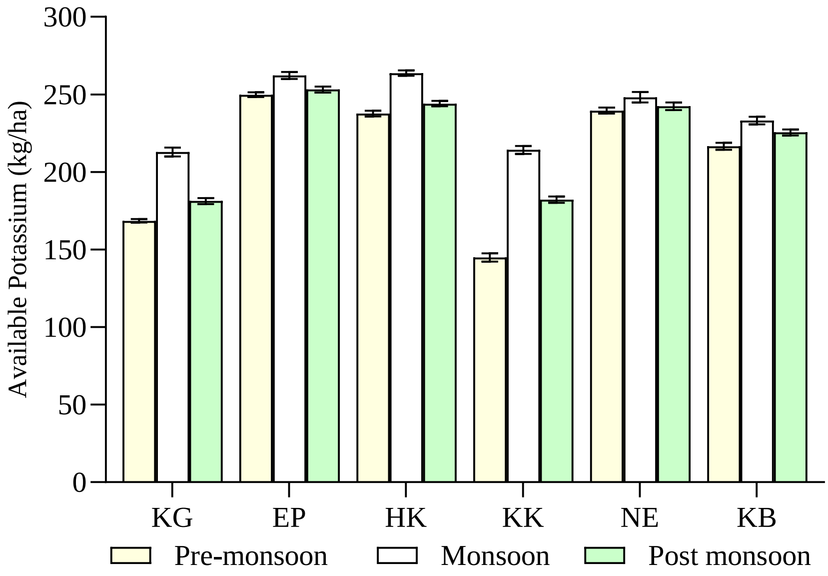


Fig 4.4.23: Available potassium content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Avail. K at the top layer ranged from 144.9 ± 2.68 (pre-monsoon) to 214.25 ± 2.55 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.10). At the subsurface layer, the Avail. K ranged from 138.28 ± 1.16 (pre-monsoon) to 211.57 ± 1.77 kg/ha (monsoon) (Fig 4.4.24) (Table 4.4.10).

At site NE, the Avail. K at the top layer ranged from 239.57 ± 1.89 (pre-monsoon) to 248.14 ± 3.39 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.11). At the subsurface layer, the Avail. K ranged from 232.03 ± 2.12 (pre-monsoon) to 243.76 ± 3.32 kg/ha (monsoon) (Fig 4.4.24) (Table 4.4.11).

At site KB, the Avail. K at the top layer ranged from 216.49 ± 2.26 (pre-monsoon) to 233.09 ± 2.42 kg/ha (monsoon) (Fig 4.4.23) (Table 4.4.12). At the subsurface layer, the Avail. K ranged from 201.83 ± 1.35 (monsoon) to 228.56 ± 0.95 kg/ha (post-monsoon) (Fig 4.4.24) (Table 4.4.12).

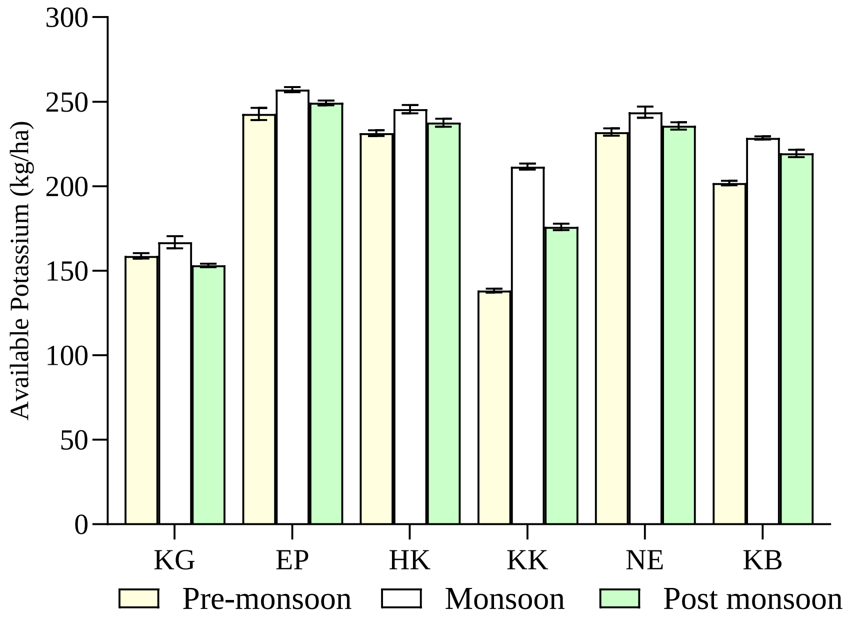


Fig 4.4.24: Available potassium content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.7. Exchangeable Sodium

In Churachandpur at site KG, the Exch. Na at the top layer ranged from 1.33 ± 0.01 (pre-monsoon) to 1.73 ± 0.01 cmol(p^+)/kg (monsoon) (Fig 4.4.25) (Table 4.4.7). At the subsurface layer, the Exch. Na ranged from 1.35 ± 0.01 (pre-monsoon) to 1.76 ± 0.01 cmol(p^+)/kg (post-monsoon) (Fig 4.4.26) (Table 4.4.7).

At site EP, the Exch. Na at the top layer ranged from 1.41 ± 0.03 (pre-monsoon) to 1.78 ± 0.01 cmol(p^+)/kg (monsoon) (Fig 4.4.25) (Table 4.4.8). At the subsurface layer, the Exch. Na ranged from 1.49 ± 0.02 (pre-monsoon) to 1.79 ± 0.04 cmol(p^+)/kg (post-monsoon) (Fig 4.4.26) (Table 4.4.8).

At site HK, the Exch. Na at the top layer ranged from 1.37 ± 0.01 (pre-monsoon) to 1.69 ± 0.01 cmol(p^+)/kg (post-monsoon) (Fig 4.4.25) (Table 4.4.9). At the subsurface layer, the Exch. Na ranged from 1.39 ± 0.02 (pre-monsoon) to 1.74 ± 0.02 cmol(p^+)/kg (post-monsoon) (Fig 4.4.26) (Table 4.4.9).

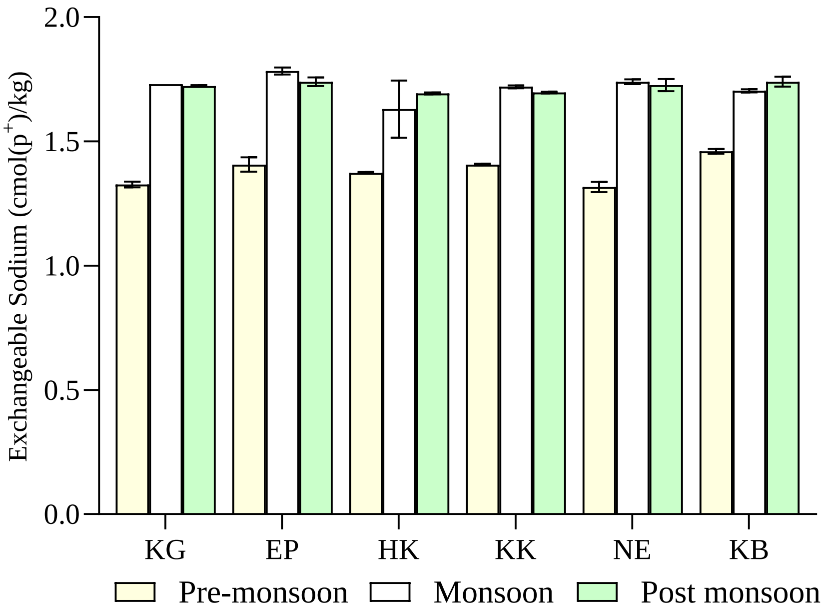


Fig 4.4.25: Exchangeable magnesium content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Exch. Na at the top layer ranged from 1.41 ± 0.01 (pre-monsoon) to 1.73 ± 0.02 cmol(p^+)/kg (post-monsoon) (Fig 4.4.25) (Table 4.4.10). At the subsurface layer, the Exch. Na ranged from 1.44 ± 0.01 (pre-monsoon) to 1.75 ± 0.01 cmol(p^+)/kg (monsoon) (Fig 4.4.26) (Table 4.4.10).

At site NE, the Exch. Na at the top layer ranged from 1.32 ± 0.02 (pre-monsoon) to 1.74 ± 0.01 cmol(p^+)/kg (monsoon) (Fig 4.4.25) (Table 4.4.11). At the subsurface layer, the Exch. Na ranged from 1.35 ± 0.01 (pre-monsoon) to 1.74 ± 0.04 cmol(p^+)/kg (post-monsoon) (Fig 4.4.26) (Table 4.4.11).

At site KB, the Exch. Na at the top layer ranged from 1.46 ± 0.01 (pre-monsoon) to 1.74 ± 0.02 cmol(p^+)/kg (post-monsoon) (Fig 4.4.25) (Table 4.4.12). At the subsurface layer, the Exch. Na ranged from 1.40 ± 0.01 (monsoon) to 1.73 ± 0.01 cmol(p^+)/kg (post-monsoon) (Fig 4.4.26) (Table 4.4.12).

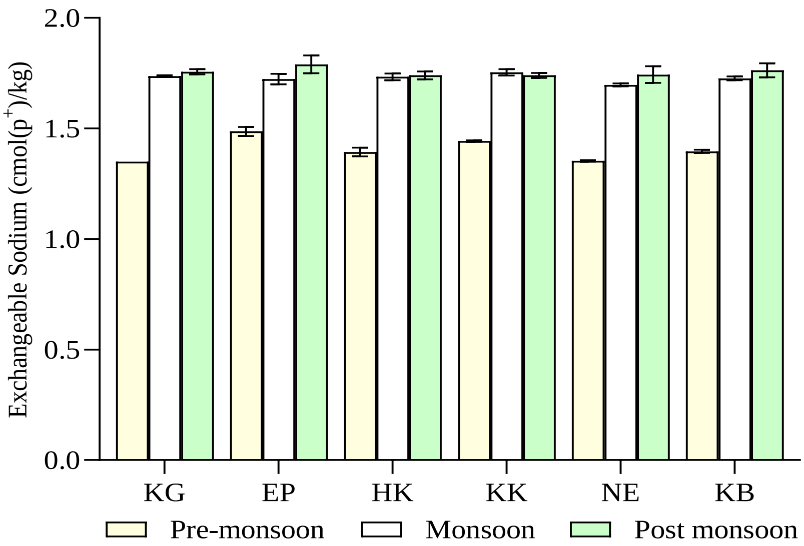


Fig 4.4.26: Exchangeable sodium content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.8. Exchangeable Calcium

In Churachandpur at site KG, the Exch. Ca at the top layer ranged from 0.83 ± 0.12 (monsoon) to 1.83 ± 0.27 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.7). At the subsurface layer, the Exch. Ca ranged from 0.63 ± 0.09 (pre-monsoon) to 1.27 ± 0.09 cmol(p^+)/kg (monsoon) (Fig 4.4.28) (Table 4.4.7).

At site EP, the Exch. Ca at the top layer ranged from 0.67 ± 0.07 (monsoon) to 1.88 ± 0.03 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.8). At the subsurface layer, the Exch. Ca ranged from 0.53 ± 0.13 (pre-monsoon) to 0.93 ± 0.02 cmol(p^+)/kg (monsoon) (Fig 4.4.28) (Table 4.4.8).

At site HK, the Exch. Ca at the top layer ranged from 0.97 ± 0.07 (post-monsoon) to 1.91 ± 0.07 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.9). At the subsurface layer, the Exch. Ca ranged from 0.7 ± 0.07 (pre-monsoon) to 1.35 ± 0.07 cmol(p^+)/kg (monsoon) (Fig 4.4.28) (Table 4.4.9).

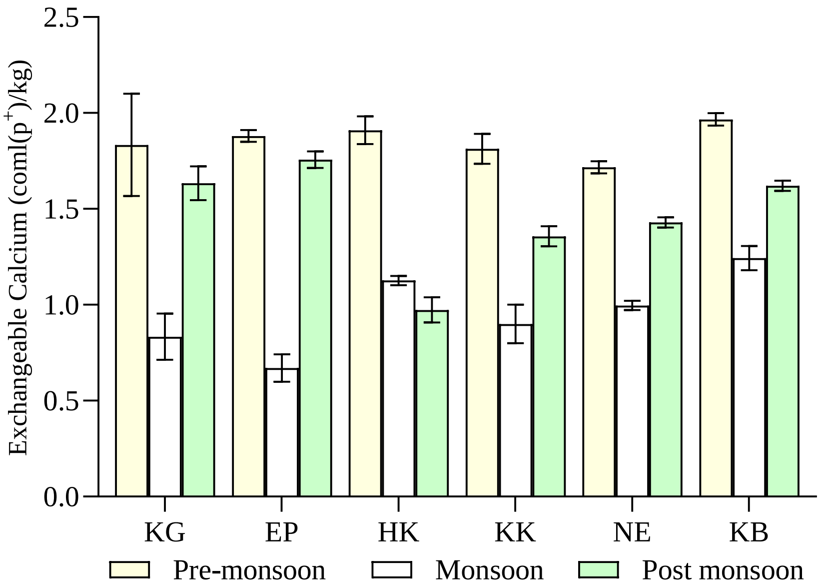


Fig 4.4.27: Exchangeable calcium content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Exch. Ca at the top layer ranged from 0.9 ± 0.10 (monsoon) to 1.81 ± 0.08 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.10). At the subsurface layer, the Exch. Ca ranged from 0.61 ± 0.09 (pre-monsoon) to 1.12 ± 0.07 cmol(p^+)/kg (monsoon) (Fig 4.4.28) (Table 4.4.10).

At site NE, the Exch. Ca at the top layer ranged from 1 ± 0.02 (monsoon) to 1.72 ± 0.03 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.11). At the subsurface layer, the Exch. Ca ranged from 0.71 ± 0.02 (pre-monsoon) to 1.34 ± 0.01 cmol(p^+)/kg (monsoon) (Fig 4.4.28) (Table 4.4.11).

At site KB, the Exch. Ca at the top layer ranged from 1.24 ± 0.06 (monsoon) to 1.97 ± 0.03 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.27) (Table 4.4.12). At the subsurface layer, the Exch. Ca ranged from 0.83 ± 0.02 (monsoon) to 1.61 ± 0.11 cmol(p^+)/kg (pre-monsoon) (Fig 4.4.28) (Table 4.4.12).

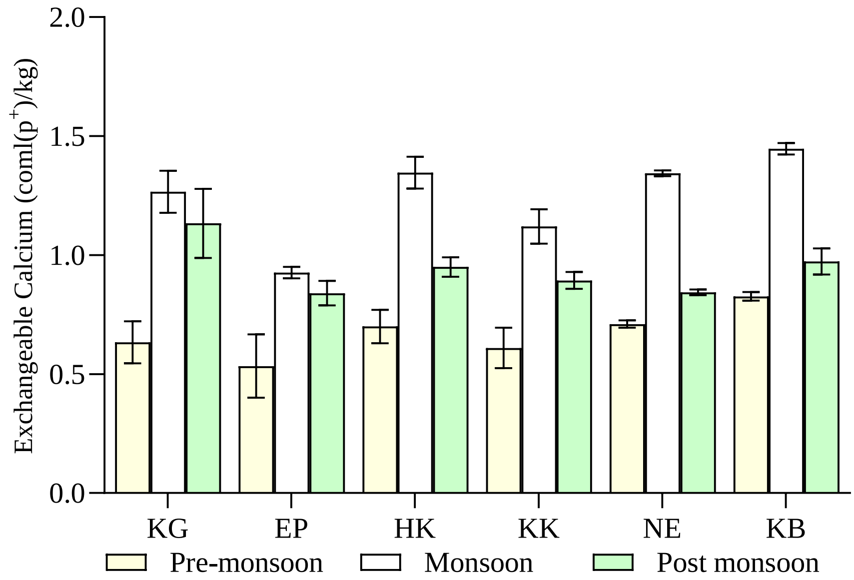


Fig 4.2.28: Exchangeable calcium content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

4.4.2.9. Exchangeable Magnesium

In Churachandpur at site KG, the Exch. Mg at the top layer ranged from 0.97 ± 0.03 (post-monsoon) to 1.33 ± 0.02 cmol(p^+)/kg (pre-monsoon) (Fig 4.2.29) (Table 4.4.7). At the subsurface layer, the Exch. Mg ranged from 1.2 ± 0.06 (pre-monsoon) to 1.6 ± 0.03 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.7).

At site EP, the Exch. Mg at the top layer ranged from 1.03 ± 0.12 (post-monsoon) to 1.57 ± 0.05 cmol(p^+)/kg (pre-monsoon) (Fig 4.2.29) (Table 4.4.8). At the subsurface layer, the Exch. Mg ranged from 1.33 ± 0.04 (pre-monsoon) to 1.66 ± 0.04 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.8).

At site HK, the Exch. Mg at the top layer ranged from 0.95 ± 0.04 (post-monsoon) to 1.36 ± 0.03 cmol(p^+)/kg (pre-monsoon) (Fig 4.2.29) (Table 4.4.9). At the subsurface layer, the Exch. Mg ranged from 1.18 ± 0.02 (pre-monsoon) to 1.37 ± 0.03 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.9).

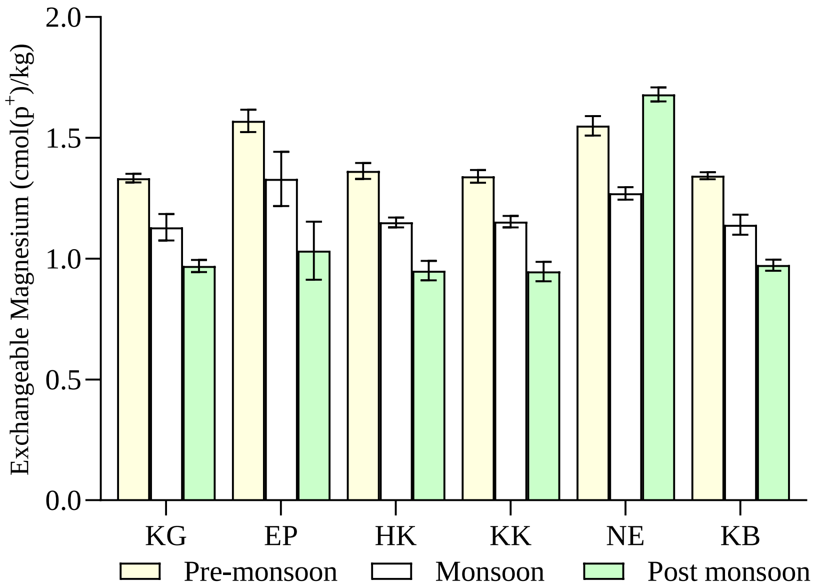


Fig 4.2.29: Exchangeable magnesium content at selected jhum fields of Churachandpur and Champhai (0-15 cm)

In Champhai at site KK, the Exch. Mg at the top layer ranged from 0.95 ± 0.04 (post-monsoon) to 1.34 ± 0.03 cmol(p^+)/kg (pre-monsoon) (Fig 4.2.29) (Table 4.4.10). At the subsurface layer, the Exch. Mg ranged from 1.19 ± 0.02 (pre-monsoon) to 1.49 ± 0.02 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.10).

At site NE, the Exch. Mg at the top layer ranged from 1.27 ± 0.03 (monsoon) to 1.68 ± 0.03 cmol(p^+)/kg (post-monsoon) (Fig 4.2.29) (Table 4.4.11). At the subsurface layer, the Exch. Mg ranged from 1.27 ± 0.05 (pre-monsoon) to 1.49 ± 0.02 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.11).

At site KB, the Exch. Mg at the top layer ranged from 0.97 ± 0.02 (post-monsoon) to 1.34 ± 0.01 cmol(p^+)/kg (pre-monsoon) (Fig 4.2.29) (Table 4.4.12). At the subsurface layer, the Exch. Mg ranged from 1.15 ± 0.06 (pre-monsoon) to 1.26 ± 0.03 cmol(p^+)/kg (post-monsoon) (Fig 4.2.30) (Table 4.4.12).

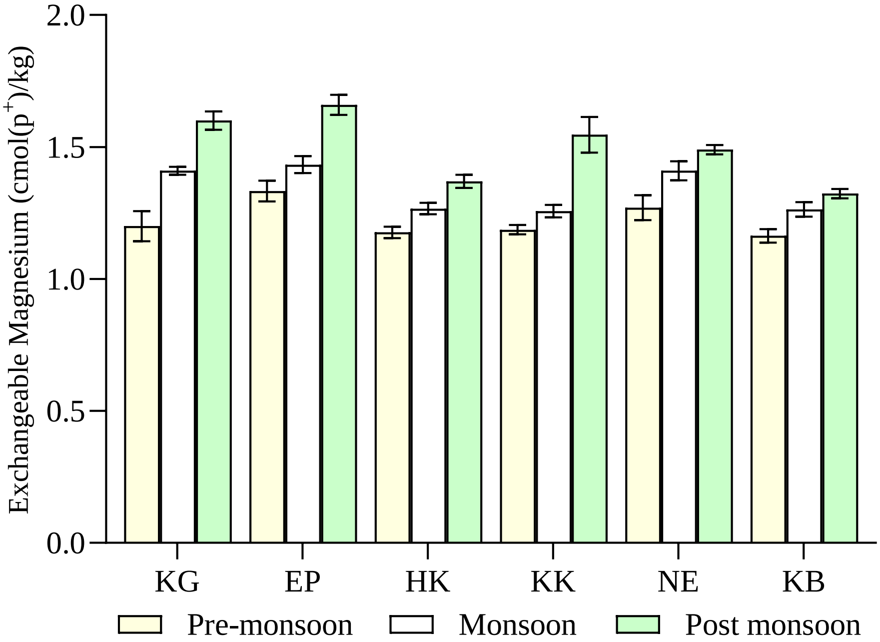


Fig 4.4.30: Exchangeable magnesium content at selected jhum fields of Churachandpur and Champhai (15-30 cm)

Table 4.4.7: Chemical properties of soil at site KG (mean ±SEM)

Depth	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na ($cmol(p^+)/kg$)	Exch. Ca ($cmol(p^+)/kg$)	Exch. Mg ($cmol(p^+)/kg$)
0-15	Pre-monsoon	6.48 ±0.03	0.24 ±0.02	2.71 ±0.04	459.95 ±27.66	27.21 ±1.15	168.47 ±1.17	1.33 ±0.01	1.83 ±0.27	1.33 ±0.02
	Monsoon	5.62 ±0.05	0.18 ±0.01	2.26 ±0.03	512.21 ±10.45	35.36 ±0.84	212.94 ±2.87	1.73 ±0.01	0.83 ±0.12	1.13 ±0.06
	Post monsoon	6.42 ±0.02	0.26 ±0.01	2.46 ±0.04	491.31 ±10.45	30.22 ±0.96	181.29 ±1.99	1.72 ±0.01	1.63 ±0.09	0.97 ±0.03
15-30	Pre-monsoon	6.35 ±0.06	0.19 ±0.02	2.16 ±0.03	407.68 ±18.11	22.44 ±0.69	158.8 ±1.57	1.35 ±0.01	0.63 ±0.09	1.2 ±0.06
	Monsoon	5.55 ±0.03	0.12 ±0.02	1.8 ±0.06	365.87 ±10.45	32.77 ±0.94	166.87 ±3.62	1.74 ±0.01	1.27 ±0.09	1.41 ±0.02
	Post monsoon	6.27 ±0.07	0.16 ±0.01	1.95 ±0.06	271.79 ±10.45	25.78 ±0.71	153.14 ±1.10	1.76 ±0.01	1.13 ±0.15	1.6 ±0.03

Table 4.4.8: Chemical properties of soil at site EP (mean ±SEM)

Depth	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na (cmol(p^+)/kg)	Exch. Ca (cmol(p^+)/kg)	Exch. Mg (cmol(p^+)/kg)
0-15	Pre-monsoon	5.9 ±0.01	0.18 ±0.02	2.22 ±0.08	313.6 ±18.11	21.66 ±0.38	249.82 ±1.58	1.41 ±0.03	1.88 ±0.03	1.57 ±0.05
	Monsoon	5.62 ±0.05	0.16 ±0.02	1.78 ±0.07	303.15 ±27.66	31.19 ±1	262.12 ±2.26	1.78 ±0.01	0.67 ±0.07	1.33 ±0.11
	Post monsoon	5.71 ±0.02	0.23 ±0.02	2.11 ±0.03	428.59 ±10.45	23.91 ±1.06	253.12 ±1.91	1.74 ±0.02	1.76 ±0.04	1.03 ±0.12
15-30	Pre-monsoon	5.7 ±0.01	0.17 ±0.02	2.07 ±0.07	271.79 ±10.45	19.44 ±1.26	242.74 ±3.52	1.49 ±0.02	0.53 ±0.13	1.33 ±0.04
	Monsoon	5.61 ±0.02	0.11 ±0.01	1.5 ±0.10	261.33 ±10.45	24.63 ±0.91	257.2 ±1.53	1.72 ±0.02	0.93 ±0.02	1.43 ±0.03
	Post monsoon	5.64 ±0.06	0.16 ±0.02	1.95 ±0.04	386.77 ±10.45	20.4 ±0.64	249.29 ±1.46	1.79 ±0.04	0.84 ±0.05	1.66 ±0.04

Table 4.4.9: Chemical properties of soil at site HK (mean ±SEM)

Depth	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na (cmol(p^+)/kg)	Exch. Ca (cmol(p^+)/kg)	Exch. Mg (cmol(p^+)/kg)
0-15	Pre-monsoon	6.41 ±0.04	0.21 ±0.02	3.03 ±0.13	324.05 ±10.45	29.05 ±0.76	237.6 ±1.82	1.37 ±0.01	1.91 ±0.07	1.36 ±0.03
	Monsoon	5.66 ±0.03	0.18 ±0.01	2.67 ±0.04	449.49 ±10.45	38.1 ±2.86	263.68 ±1.76	1.63 ±0.12	1.13 ±0.02	1.15 ±0.02
	Post monsoon	6.23 ±0.04	0.23 ±0.02	2.96 ±0.08	616.75 ±10.45	32.26 ±0.0	244.08 ±1.68	1.69 ±0.01	0.97 ±0.07	0.95 ±0.04
15-30	Pre-monsoon	6.26 ±0.18	0.14 ±0.02	2.69 ±0.10	219.52 ±18.11	22.44 ±0.50	231.4 ±1.65	1.39 ±0.02	0.7 ±0.07	1.18 ±0.02
	Monsoon	5.57 ±0.57	0.12 ±0.02	2.34 ±0.02	334.51 ±10.45	34.13 ±0.73	245.62 ±2.47	1.73 ±0.01	1.35 ±0.07	1.27 ±0.02
	Post monsoon	6.1 ±0.12	0.15 ±0.02	3.53 ±0.17	533.12 ±18.11	29.15 ±0.77	237.57 ±2.34	1.74 ±0.02	0.95 ±0.04	1.37 ±0.03

Table 4.4.10: Chemical properties of soil at KK (mean ±SEM)

Depths	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na ($cmol(p^+)/kg$)	Exch. Ca ($cmol(p^+)/kg$)	Exch. Mg ($cmol(p^+)/kg$)
0-15	Pre-monsoon	5.8 ±0.04	0.23 ±0.02	2.08 ±0.07	156.8 ±18.11	21.8 ±1.11	144.9 ±2.68	1.41 ±0.01	1.81 ±0.08	1.34 ±0.03
15-30		5.76 ±0.04	0.18 ±0.03	0.98 ±0.07	135.89 ±10.45	19.77 ±1.06	138.28 ±1.16	1.44 ±0.01	0.61 ±0.09	1.19 ±0.02
0-15	Monsoon	5.6 ±0.04	0.17 ±0.02	1.89 ±0.09	449.49 ±10.45	33.61 ±1.02	214.25 ±2.55	1.72 ±0.01	0.9 ±0.10	1.15 ±0.02
15-30		5.54 ±0.03	0.11 ±0.02	0.76 ±0.10	321.51 ±19.76	25.46 ±0.82	211.57 ±1.77	1.75 ±0.01	1.12 ±0.07	1.26 ±0.02
0-15	Post monsoon	5.63 ±0.04	0.24 ±0.04	1.96 ±0.06	240.43 ±27.66	26.61 ±0.42	182.14 ±2.01	1.7 ±0.01	1.36 ±0.05	0.95 ±0.04
15-30		5.59 ±0.01	0.16 ±0.03	0.85 ±0.08	229.97 ±20.91	21.78 ±0.0	175.9 ±1.89	1.74 ±0.01	0.89 ±0.04	1.49 ±0.02

Table 4.4.11: Chemical properties of soil at NE (mean ±SEM)

Depths	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na (cmol(p^+)/kg)	Exch. Ca (cmol(p^+)/kg)	Exch. Mg (cmol(p^+)/kg)
0-15	Pre-monsoon	6.21 ±0.02	0.21 ±0.01	2.88 ±0.20	397.23 ±37.69	19.85 ±0.76	239.57 ±1.89	1.32 ±0.02	1.72 ±0.03	1.55 ±0.04
	Monsoon	5.57 ±0.02	0.15 ±0.02	2.29 ±0.10	501.76 ±18.11	27.15 ±1.51	248.14 ±3.39	1.74 ±0.01	1 ±0.02	1.27 ±0.03
	Post monsoon	5.97 ±0.07	0.24 ±0.03	2.66 ±0.06	376.32 ±18.11	24.72 ±0.41	242.41 ±2.2	1.73 ±0.02	1.43 ±0.03	1.68 ±0.03
15-30	Pre-monsoon	5.85 ±0.03	0.19 ±0.02	2.12 ±0.04	344.96 ±18.11	18.1 ±0.48	232.03 ±2.12	1.35 ±0.01	0.71 ±0.02	1.27 ±0.05
	Monsoon	5.48 ±0.03	0.12 ±0.02	1.69 ±0.03	428.59 ±10.45	25.02 ±0.62	243.76 ±3.32	1.7 ±0.01	1.34 ±0.01	1.41 ±0.04
	Post monsoon	5.66 ±0.03	0.17 ±0.01	1.25 ±0.03	219.52 ±36.21	23.06 ±0.23	235.65 ±2.22	1.74 ±0.04	0.84 ±0.01	1.49 ±0.02

Table 4.4.12: Chemical properties of soil at KB (mean ±SEM)

Depth	Seasons	pH	EC (dSm^{-1})	SOC (%)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Exch. Na (cmol(p^+)/kg)	Exch. Ca (cmol(p^+)/kg)	Exch. Mg (cmol(p^+)/kg)
0-15	Pre-monsoon	6.18 ±0.01	0.22 ±0.02	2.92 ±0.04	439.04 ±18.11	25.31 ±1.07	216.49 ±2.26	1.46 ±0.01	1.97 ±0.03	1.34 ±0.01
	Monsoon	5.65 ±0.04	0.17 ±0.03	2.31 ±0.03	669.01 ±20.91	35.75 ±1.16	233.09 ±2.42	1.70 ±0.01	1.24 ±0.06	1.14 ±0.04
	Post monsoon	5.97 ±0.09	0.24 ±0.02	2.59 ±0.29	407.64 ±18.14	29.29 ±1.05	225.54 ±1.92	1.74 ±0.02	1.62 ±0.03	0.97 ±0.02
15-0	Pre-monsoon	5.93 ±0.08	0.21 ±0.02	2.61 ±0.12	505.23 ±42.29	30.12 ±1.62	225.04 ±2.64	1.63 ±0.04	1.61 ±0.11	1.15 ±0.06
	Monsoon	5.84 ±0.01	0.19 ±0.02	2.66 ±0.02	250.88 ±18.11	23.47 ±0.80	201.83 ±1.35	1.40 ±0.01	0.83 ±0.02	1.16 ±0.03
	Post monsoon	5.59 ±0.02	0.13 ±0.02	2.26 ±0.26	637.65 ±27.66	33.23 ±0.20	228.56 ±0.95	1.73 ±0.01	1.45 ±0.02	1.26 ±0.03

4.4.3. Correlation Analysis

4.4.3.1. Churachandpur

Pearson Correlation analysis was carried out to determine the correlation between the soil parameters along with altitude, depth and seasons of current jhum fields of Churachandpur, Manipur. The results of the correlation analysis are presented below.

Altitude showed positive correlation with SMC (r = .691, $p< 0.01$), SOC (r = .521, $p< 0.01$), and Avail. K (r = .754, $p< 0.01$), however it showed negative correlation with clay (r = -.510, $p< 0.01$) and BD (r = -.430, $p< 0.01$). Depth was positively correlated with BD (r = .491, $p< 0.01$) and Exch. Mg (r = .425, $p< 0.01$); however, it was negatively correlated with EC (r = -.609, $p< 0.01$), Avail. N (r = -.435, $p< 0.01$), Avail. P (r = -.377, $p< 0.01$), and Exch. Ca (r = -.506, $p< 0.01$) (Table 4.4.13). Seasons also showed a positive correlation with clay (r = .665, $p< 0.01$), WHC (r = .589, $p< 0.01$), Avail. N (r = .461, $p< 0.01$), and Exch. Na (r = .828, $p< 0.01$) (Appendix I).

The sand content showed a positive correlation with Avail. P (r = .384, $p< 0.01$), and negative for silt (r = -.831, $p< 0.01$) and Avail. N (r = -.375, $p< 0.01$). Silt content was positively correlated with SOC (r = .425, $p< 0.01$), but negatively correlated with sand (r = -.831, $p< 0.01$), clay (r = -.669, $p< 0.01$), Avail. P (r = -.382, $p< 0.01$), and Exch. Na (r = -.360, $p< 0.01$) (Table 4.4.13). The clay content showed a positive correlation with the season (r = .665, $p< 0.01$) and Exch. Na (r = .585, $p< 0.01$) whereas, it is negative with altitude (r = -.510, $p< 0.01$), and silt (r = -.669, $p< 0.01$) (Appendix I).

SMC was positively correlated with altitude (r = .691, $p< 0.01$), Avail. P (r = .441, $p< 0.01$), and Avail. K (r = .667, $p< 0.01$). In contrast, WHC was positively correlated with season (r = .589, $p< 0.01$), Avail. N (r = .642, $p< 0.01$), and Exch. Na (r = .546, $p< 0.01$) but is however negative with depth (r = -.537, $p< 0.01$) (Table 4.4.13). BD was positively correlated with depth (r = .491, $p< 0.01$), Exch. Na (r = .393, $p< 0.01$) and Exch. Mg (r = .372, $p< 0.01$) but showed negative correlation with altitude (-.430, $p< 0.01$), pH (r = -.509, $p< 0.01$), EC (r = -.420, $p< 0.01$), SOC (r = -.583, $p< 0.01$) and Exch. Ca (r = -.400, $p< 0.01$) (Appendix I).

Soil pH in Churachandpur was positively correlated with EC (r = .541, $p < 0.01$) and SOC (r = .463, $p < 0.01$), and negatively correlated with BD (-.509, $p < 0.01$), Avail. K (-.430, $p < 0.01$), and Exch. Na (r = -.461, $p < 0.01$) (Table 4.4.13). EC showed a positive correlation with pH (r = .541, $p < 0.01$), Avail. N (r = .499, $p < 0.01$), and Exch. Ca (r = .421, $p < 0.01$) but is negative with depth (r = -.609, $p < 0.01$), BD (r = -.420, $p < 0.01$), and Exch. Mg (r = -.388, $p < 0.01$) (Appendix I).

The SOC showed positive correlation with altitude (r = .521, $p < 0.01$), silt (r = .425, $p < 0.01$), pH (r = .463, $p < 0.01$), Avail. N (r = .5.5, $p < 0.01$) and negative with BD (r = -.583, $p < 0.01$). Avail. N was positively correlated with season (r = .461, $p < 0.01$), EC (r = .499, $p < 0.01$), WHC (r = .642, $p < 0.01$), SOC (r = .505, $p < 0.01$), and Avail. P (r = .452, $p < 0.01$), and negatively correlated with depth (r = -.435, $p < 0.01$), sand (r = -.375, $p < 0.01$), and Exch. Mg (r = -.478, $p < 0.01$). The Avail. P was positively correlated with sand (r = .384, $p < 0.01$), SMC (r = .441, $p < 0.01$), WHC (r = .748, $p < 0.01$), and Avail. N (r = .452, $p < 0.01$) and negatively correlated with depth (r = -.377, $p < 0.01$), silt (r = -.382, $p < 0.01$), and Exch. Mg (r = -.365, $p < 0.01$). The Avail. K showed positive correlation with altitude (r = 754, $p < 0.01$) and SMC (r = .667, $p < 0.01$) but negative with pH (r = -.430, $p < 0.01$) (Appendix I).

The Exch. Na showed positive correlation with seasons (r = .828, $p < 0.01$), clay (r = .585, $p < 0.01$), WHC (r = .546, $p < 0.01$) and BD (r = .393, $p < 0.01$) and negative correlation with silt (r = -.360, $p < 0.01$) and pH (r = -.461, $p < 0.01$). The Exch. Ca showed positive correlation with EC (r = .421, $p < 0.01$), but is negatively correlated with depth (r = -.506, $p < 0.01$) and BD (r = -.400, $p < 0.01$). The Exch. Mg, however, showed a positive correlation with depth (r = .425, $p < 0.01$) and BD (r = .372, $p < 0.01$) but negatively correlated with EC (r = -.388, $p < 0.01$) and Avail. N (r = -.478, $p < 0.01$) (Appendix I).

4.4.3.2 Champhai

Pearson Correlation analysis was carried out to determine the correlation between the soil parameters along with the altitude, depth and seasons of current jhum fields of Champhai, Mizoram. The results of the correlation analysis are presented below.

Altitude was positively correlated with SMC (r = 384, $p< 0.01$), WHC (r = .541, $p< 0.01$), pH (r = .369, $p< 0.01$), SOC (r = .663, $p< 0.01$), and Avail. N (r = .572, $p< 0.01$), Avail. P (r = .352, $p< 0.01$) and Avail. K (r = .550, $p< 0.01$) but is however negative with BD (r = -.916, $p< 0.01$). Depth showed negative correlation with SMC (r = -.521, $p< 0.01$), WHC (r = -.360, $p< 0.01$), pH (r = -.366, $p< 0.01$), EC (r =-.494, $p< 0.01$), SOC (r = -.533, $p<0.01$) and Exch. Ca (r = -.603, $p< 0.01$) (Table 4.4.14). Seasons showed a positive correlation with clay content (r = .348, $p< 0.01$), WHC (r = .582, $p< 0.01$), and Exch. Na (r = .854, $p< 0.01$) but is negatively correlated with sand (r = -.396, $p< 0.01$) (Appendix II).

The sand content showed a positive correlation with Avail. N (r = 608, $p< 0.01$), Avail. P (r = .351, $p< 0.01$) and Avail. K (r = .430, $p< 0.01$) but showed negative relation with sand (r = -.396, $p< 0.01$) and silt (r = -.870, $p< 0.01$). The silt content was positively correlated with pH (r = 377, $p< 0.01$) and EC (r = .483, $p< 0.01$), and negatively correlated with sand (r = -.870, $p< 0.01$), clay (r = -.352, $p< 0.01$), SMC (r = -.543, $p< 0.01$), and Avail. N (r = .709, $p< 0.01$), Avail. P (r = -.414, $p< 0.01$) and Avail. K (r = -.528, $p< 0.01$). The clay content showed a positive correlation with season (r = .348, $p< 0.01$) and Exch. Na (r = .503, $p< 0.01$) but is however negatively correlated with silt content (r = -.352, $p< 0.01$), pH (r = -.481, $p< 0.01$) and EC (r = -.377, $p< 0.01$) (Appendix II).

SMC showed a positive correlation with altitude (r = 384, $p< 0.01$), sand (r = .417, $p< 0.01$), WHC (r = .539, $p< 0.01$), SOC (r = .420, $p< 0.01$), and Avail. N (r = .735, $p< 0.01$), Avail. P (r = .446, $p< 0.01$) and Avail. K (r = .668, $p< 0.01$) but have negative correlation with silt (r = -.543, $p< 0.01$) and BD (r = -.385, $p< 0.01$). The WHC was positively correlated with altitude (r = .541, $p< 0.01$), season (r = .582, $p< 0.01$), SMC (r = .539, $p< 0.01$), and Avail. N (r = .609, $p< 0.01$), Avail. P (r = .614, $p< 0.01$), Avail. K (r = .606, $p< 0.01$) and Exch. Na (r = .572, $p< 0.01$) but showed negative correlation with depth (r = -.360, $p < 0.01$) and BD (r = -.440, $p < 0.01$).However, BD was negatively correlated with altitude (r = -.916, $p < 0.01$), SMC (r = -.385, $p < 0.01$), WHC (r = -.440, $p < 0.01$), pH (r =-.555, $p < 0.01$), SOC (r = -.727, $p < 0.01$), and Avail. N (r =-.389, $p < 0.01$), Avail. K (r =-.474, $p < 0.01$) and Exch. Ca (r =-.333, $p < 0.01$) (Appendix II).

pH was positively correlated with altitude (r = .369, $p < 0.01$), silt content (r = .377, $p < 0.01$), EC (r = .596, $p < 0.01$), SOC (r = .643, $p < 0.01$), and Exch Ca (r = .468, $p < 0.01$) but negatively correlated with depth (r = -.366, $p < 0.01$), clay content (r = -.481, $p < 0.01$), BD (r = -.555, $p < 0.01$), and Exch. Na (r = -.569, $p < 0.01$). EC was positively correlated with silt content (r = .483, $p < 0.01$), pH (r = .596, $p < 0.01$), SOC (r = .423, $p < 0.01$), and Exch. Ca (r = .364, $p < 0.01$) but is negatively correlated with depth (r = -.494, $p < 0.01$) and clay content (r = -.377, $p < 0.01$) (Appendix II).

SOC was positively correlated with altitude (r = .663, $p < 0.01$), SMC (r = .420, $p < 0.01$), pH (r = .643, $p < 0.01$), EC (r = .423, $p < 0.01$), and Avail. N (.416, $p < 0.01$), Avail. K (r = .413, $p < 0.01$) and Exch. Ca (r = .534, $p < 0.01$) but is negatively correlated with depth (r = -.533, $p < 0.01$) and BD (r = -.727, $p < 0.01$). The Avail. N was positively correlated with altitude (r = .572, $p < 0.01$), sand content (r = .608, $p < 0.01$), SMC (r = .735, $p < 0.01$), WHC (r = .609, $p < 0.01$), SOC (r = .416, $p < 0.01$), Avail P (r = .712, $p < 0.01$), and Avail. K (r = .681, $p < 0.01$) but is however negatively correlated with silt content (r = -.709, $p < 0.01$) and BD (r = -.389, $p < 0.01$). The Avail. P was positively correlated with altitude (r = .352, $p < 0.01$), sand content (r = .351, $p < 0.01$), SMC (r = .446, $p < 0.01$), WHC (r = .614, $p < 0.01$), and Exch. Na (r = .598, $p < 0.01$) but is negatively correlated with silt content (r = -.414, $p < 0.01$) and Exch. Mg (r = -.389, $p < 0.01$) (Table 4.4.14). The Avail. K was positively correlated with altitude (r = .550, $p < 0.01$), sand content (r = .430, $p < 0.01$), SMC (r = .668, $p < 0.01$), WHC (r = .606, $p < 0.01$), SOC (r = .413, $p < 0.01$), and Avail. N (r = .681, $p < 0.01$) but showed negative correlation with silt content (r = -.528, $p < 0.01$) and BD (r = -.474, $p < 0.01$) (Appendix II).

Exch. Na showed a positive correlation with season (r = .854, $p < 0.01$), clay content (r = .503, $p < 0.01$), WHC (r = .572, $p < 0.01$), and Avail. P (r = .598, $p < 0.01$) but is negatively correlated with pH (r = -.569, $p < 0.01$). The Exch. Ca showed positive correlation with pH (r = .468, $p < 0.01$) and EC (r = .364, $p < 0.01$) and is negatively correlated with depth (r = -.603, $p < 0.01$). The Exch. Mg was negatively correlated with Avail. P (r = -.39, $p < 0.01$) (Appendix II).

4.4.4. Analysis of variance (ANOVA) and post-hoc tests

4.4.4.1. Churachandpur

4.4.4.1.1. Altitude: The analysis of variance (ANOVA) revealed significant differences in various soil parameters across different altitudes and seasons in the jhum fields of Churachandpur. The ANOVA revealed a significant difference in sand content among different altitudes ($F(2, 51) = 5.00$, $p = 0.01$) (Appendix III), with the mean difference between 344 m and 829 m being -6.18%, and between 344 m and 1579 m being -4.86% ($p < 0.001$) (Appendix V). The silt content was significantly different across altitudes ($F(2, 51) = 3.60$, $p = 0.03$) (Appendix III), with the mean difference between 344 m and 829 m being 5.97%, and between 344 m and 1579 m being 3.04% ($p < 0.001$) (Appendix V).The clay content showed a highly significant difference between altitudes ($F(2, 51) = 30.47$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being 0.22% ($p < 0.001$), and between 344 m and 1579 m being 1.83% ($p < 0.001$) (Appendix V).

The SMC varied significantly among altitudes ($F(2, 51) = 8.23$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -4.33% ($p < 0.001$), and between 344 m and 1579 m being -3.61% ($p < 0.001$) (Appendix V). The WHC of the soil showed a highly significant difference across altitudes ($F(2, 51) = 11.15$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -3.03% ($p < 0.001$), and between 344 m and 1579 m being -4.54% ($p < 0.001$) (Appendix V). The BD of the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 140.24$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being 0.23 g/cm^3 ($p < 0.001$), and between 344 m and 1579 m being 0.40 g/cm^3 ($p < 0.001$) (Appendix V).

The soil pH exhibited a significant difference across altitudes ($F(2, 51) = 4.25$, $p = 0.02$) (Appendix III), with the mean difference between 344 m and 829 m being -0.14 ($p < 0.001$), and between 344 m and 1579 m being -0.19 ($p < 0.001$) (Appendix V). The SOC content in the soil showed a highly significant difference across altitudes ($F(2, 51) = 21.18$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -0.73% ($p < 0.001$), and between 344 m and 1579 m being -1.11% ($p < 0.001$) (Appendix V). The Avail. N content in the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 12.62$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -122.38 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -206.00 kg/ha ($p < 0.001$) (Appendix V). The Avail. P content in the soil showed a highly significant difference across altitudes ($F(2, 51) = 9.37$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being 1.86 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -4.24 kg/ha ($p < 0.001$) (Appendix V). The Avail. K content in the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 51.20$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -62.42 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -42.97 kg/ha ($p < 0.001$) (Appendix V). The Exch. Mg content in the soil showed a significant difference across altitudes ($F(2, 51) = 12.74$, $p < 0.001$) (Appendix III), with the mean difference between 344 m and 829 m being -0.22 cmol(p^+)/kg ($p < 0.001$), and between 344 m and 1579 m being non-significant ($p = 0.10$) (Appendix V).

4.4.4.1.2.Seasons: ANOVA revealed significant differences in various soil parameters across the seasons. The sand content exhibited a highly significant difference among different seasons ($F(2, 51) = 32.29$, $p < 0.001$) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -5.65% ($p < 0.001$), and between pre-monsoon and post monsoon being 6.36% ($p < 0.001$) (Appendix VI). The silt content showed a highly significant difference across different seasons ($F(2, 51) = 83.47$, $p < 0.001$) (Appendix IV), with a mean difference between pre-monsoon and monsoon of 10.81% ($p < 0.001$), and between pre-monsoon and post monsoon (-3.43%, $p < 0.001$) (Appendix VI). The clay content exhibited a highly significant difference among different seasons ($F(2, 51) = 15.49$, $p < 0.001$) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -

5.16% (p< 0.001), and between pre-monsoon and post monsoon being -2.93% (p< 0.001) (Appendix VI).

The SMC showed a highly significant difference among different seasons ($F(2, 51) = 8.45$, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -3.55% (p< 0.001), and between pre-monsoon and post monsoon being 0.88% (p = 0.04) (Appendix VI). The WHC of the soil exhibited a highly significant difference across different seasons ($F(2, 51) = 16.61$, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -4.15% (p< 0.001), and between pre-monsoon and post monsoon being -4.88% (p< 0.001) (Appendix VI).

The soil pH showed a highly significant difference among different seasons ($F(2, 51) = 24.95$, p< 0.001) (Appendix IV), with the mean difference between the pre-monsoon and monsoon being 0.37 (p< 0.001), and between the pre-monsoon and post monsoon being 0.16 (p< 0.001) (Appendix VI). The EC of the soil exhibited a highly significant difference across different seasons ($F(2, 51) = 11.68$, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being 0.06 dSm^{-1} (p< 0.001), and between pre-monsoon and post monsoon being non-significant (p = 0.84) (Appendix VI).

The SOC content in the soil showed a significant difference among the different seasons ($F(2, 51) = 3.47$, p = 0.04) (Appendix IV), with the mean difference between pre-monsoon and monsoon being 0.41% (p< 0.001), and between pre-monsoon and post monsoon being 0.32% (p< 0.001) (Appendix VI). The Avail. N content exhibited a highly significant difference across seasons ($F(2, 51) = 19.39$, p< 0.001) (Appendix IV), with a mean difference between pre-monsoon and monsoon of -213.87 kg/ha (p< 0.001), and between pre-monsoon and post monsoon being non-significant (p = 0.14) (Appendix VI). The Avail. P content showed a highly significant difference among seasons ($F(2, 51) = 27.15$, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -8.65 kg/ha (p< 0.001), and between pre-monsoon and post monsoon being -4.10 kg/ha (p< 0.001) (Appendix VI). The Avail. K content exhibited a highly significant difference across seasons ($F(2, 51) = 6.12$, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -34.38 kg/ha (p< 0.001), and between pre-monsoon and post monsoon being -17.99 kg/ha (p< 0.001) (Appendix VI).

The Exch. Na content showed a highly significant difference among seasons (F(2, 51) = 395.62, p< 0.001) (Appendix IV), with the mean difference between pre-monsoon and monsoon being -0.33 cmol(p^+)/kg (p< 0.001), and between pre-monsoon and post monsoon being -0.34 cmol(p^+)/kg (p< 0.001) (Appendix VI). The Exch. Ca content exhibited a significant difference across seasons (F(2, 51) = 3.31, p = 0.04) (Appendix IV), with the mean difference between pre-monsoon and monsoon being 0.10 cmol(p^+)/kg (p< 0.001), and between pre-monsoon and post monsoon being 0.09 cmol(p^+)/kg (p< 0.001) (Appendix VI). The Exch. Mg content showed a highly significant difference among seasons (F(2, 51) = 6.11, p = 0.004) (Appendix IV), with the mean difference between pre-monsoon and monsoon being 0.06 cmol(p^+)/kg (p< 0.001), and between pre-monsoon and post monsoon being non-significant (p = 0.60) (Appendix VI).

4.4.4.2. Champhai

4.4.4.2.1. Altitude: The analysis of variance (ANOVA) revealed significant differences in various soil parameters across different altitudes and seasons in the jhum fields of Champhai. The sand content exhibited a significant difference among different altitudes (F(2, 51) = 5.00, p = 0.01) (Appendix VII), with the mean difference between 344 m and 829 m being -6.18%, and between 344 m and 1579 m being -4.86% (p< 0.001) (Appendix IX). The silt content also varied significantly across altitudes (F(2, 51) = 3.60, p = 0.03) (Appendix VII), with the mean difference between 344 m and 829 m being 5.97%, and between 344 m and 1579 m being 3.04% (p< 0.001) (Appendix IX).The clay content showed a significant difference between altitudes (F(2, 51) = 30.47, p< 0.001) (Appendix VII), with the mean difference between 344 m and 829 m being 0.22% (p< 0.001) (Appendix IX), and between 344 m and 1579 m being 1.83% (p< 0.001) (Appendix IX).

The SMC varied significantly among altitudes (F(2, 51) = 8.23, p< 0.001) (Appendix VII), with the mean difference between 344 m and 829 m being -4.33% (p< 0.001), and between 344 m and 1579 m being -3.61% (p< 0.001) (Appendix IX).

The WHC of the soil showed a highly significant difference across altitudes ($F(2, 51) = 11.15$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being -3.03% ($p < 0.001$), and between 344 m and 1579 m being -4.54% ($p < 0.001$) (Appendix IX). The BD of the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 140.24$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being 0.23 g/cm³ ($p < 0.001$), and between 344 m and 1579 m being 0.40 g/cm³ ($p < 0.001$) (Appendix IX).

The soil pH exhibited a significant difference across altitudes ($F(2, 51) = 4.25$, $p = 0.02$) (Appendix VII), with the mean difference between 344 m and 829 m being -0.14 ($p < 0.001$), and between 344 m and 1579 m being -0.19 ($p < 0.001$) (Appendix IX). The SOC content in the soil showed a highly significant difference across altitudes ($F(2, 51) = 21.18$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being -0.73% ($p < 0.001$), and between 344 m and 1579 m being -1.11% ($p < 0.001$) (Appendix IX). The Avail. N content in the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 12.62$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being -122.38 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -206.00 kg/ha ($p < 0.001$) (Appendix IX). The Avail. P content in the soil showed a highly significant difference across altitudes ($F(2, 51) = 9.37$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being 1.86 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -4.24 kg/ha ($p < 0.001$) (Appendix IX). The Avail. K content in the soil exhibited a highly significant difference among altitudes ($F(2, 51) = 51.20$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being -62.42 kg/ha ($p < 0.001$), and between 344 m and 1579 m being -42.97 kg/ha ($p < 0.001$) (Appendix IX). The Exch. Na content in the soil showed a significant difference across altitudes ($F(2, 51) = 3.99$, $p = 0.02$) (Appendix VII), with the mean difference between 344 m and 829 m being 0.03 cmol(p^+)/kg ($p < 0.001$), and between 344 m and 1579 m being non-significant ($p = 0.59$) (Appendix IX). The Exch. Ca content in the soil exhibited a significant difference among altitudes ($F(2, 51) = 5.27$, $p = 0.01$) (Appendix VII), with the mean difference between 344 m and 829 m being non-significant ($p = 0.05$), and between 344 m and 1579 m being -0.23

cmol(p^+)/kg ($p < 0.001$) (Appendix IX). The Exch. Mg content in the soil showed a highly significant difference across altitudes ($F(2, 51) = 12.74$, $p < 0.001$) (Appendix VII), with the mean difference between 344 m and 829 m being -0.22 cmol(p^+)/kg ($p < 0.001$), and between 344 m and 1579 m being non-significant ($p = 0.10$) (Appendix IX).

4.4.4.2.2.Seasons: ANOVA revealed significant differences in various soil parameters across the seasons. The sand content exhibited a highly significant difference among different seasons ($F(2, 51) = 32.29$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -5.65% ($p < 0.001$), and between pre-monsoon and post monsoon being 6.36% ($p < 0.001$) (Appendix X). The silt content showed a highly significant difference across different seasons ($F(2, 51) = 83.47$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being 10.81% ($p < 0.001$) and between pre-monsoon and post monsoon (-3.43%, $p < 0.001$) (Appendix X). The clay content exhibited a highly significant difference among different seasons ($F(2, 51) = 15.49$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -5.16% ($p < 0.001$), and between pre-monsoon and post monsoon being -2.93% ($p < 0.001$) (Appendix X). The SMC showed a highly significant difference among different seasons ($F(2, 51) = 8.45$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -3.55% ($p < 0.001$), and between pre-monsoon and post monsoon being 0.88% ($p = 0.04$) (Appendix X). The WHC of the soil exhibited a highly significant difference across different seasons ($F(2, 51) = 16.61$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -4.15% ($p < 0.001$), and between pre-monsoon and post monsoon being -4.88% ($p < 0.001$) (Appendix X).

The soil pH showed a highly significant difference among the different seasons ($F(2, 51) = 24.95$, $p < 0.001$) (Appendix VIII), with the mean difference between the pre-monsoon and monsoon periods being 0.37% ($p < 0.001$), and between the pre-monsoon and post monsoon being 0.16 ($p < 0.001$) (Appendix X). The EC of the soil exhibited a highly significant difference across different seasons ($F(2, 51) = 11.68$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being 0.06 dSm^{-1} ($p < 0.001$), and between pre-monsoon and post monsoon being non-significant ($p = 0.84$) (Appendix X). The SOC content in the soil showed a significant difference among the different seasons ($F(2, 51) = 3.47$, $p = 0.04$) (Appendix VIII), with a mean difference between the pre-monsoon and monsoon periods of 0.41% ($p < 0.001$), and between the pre-monsoon and post monsoon periods of 0.32% ($p < 0.001$) (Appendix X). The Avail. N content exhibited a highly significant difference across seasons ($F(2, 51) = 19.39$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -213.87 kg/ha ($p < 0.001$), and between pre-monsoon and post monsoon being non-significant ($p = 0.14$) (Appendix X). The Avail. P content showed a highly significant difference among seasons ($F(2, 51) = 27.15$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -8.65 kg/ha ($p < 0.001$), and between pre-monsoon and post monsoon being -4.10 kg/ha ($p < 0.001$) (Appendix X). The Avail. K content exhibited a highly significant difference across seasons ($F(2, 51) = 6.12$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -34.38 kg/ha ($p < 0.001$) (Appendix X), and between pre-monsoon and post monsoon being -17.99 kg/ha ($p < 0.001$) (Appendix X).

The Exch. Na content showed a highly significant difference among seasons ($F(2, 51) = 395.62$, $p < 0.001$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being -0.33 cmol(p^+)/kg ($p < 0.001$), and between pre-monsoon and post monsoon being -0.34 cmol(p^+)/kg ($p < 0.001$) (Appendix X). The Exch. Ca content exhibited a significant difference across seasons ($F(2, 51) = 3.31$, $p = 0.04$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being 0.10 cmol(p^+)/kg ($p < 0.001$), and between pre-monsoon and post monsoon being 0.09 cmol(p^+)/kg ($p < 0.001$) (Appendix X). The Exch. Mg content showed a highly significant difference among seasons ($F(2, 51) = 6.11$, $p = 0.004$) (Appendix VIII), with the mean difference between pre-monsoon and monsoon being 0.06 cmol(p^+)/kg ($p < 0.001$), and between pre-monsoon and post monsoon being non-significant ($p = 0.60$) (Appendix X).

ANOVA and LSD post-hoc tests revealed that various soil properties, including texture, pH, EC, SMC, BD, SOC, available macronutrients, and exchangeable cations, exhibited statistically significant differences across altitudes and seasons in the jhum fields of Champhai.

4.4.4.3. Comparative analysis of soil quality

4.4.4.3.1. Site KG and Site KK (<500 m)

4.4.4.3.1.1.Pre-monsoon Season: At 0-15 cm depth, KG had a higher clay content (8.20 ± 0.04%), while KK had a higher sand (81.18 ± 0.06%) and silt (16.33 ± 0.06%) content. KG also had higher SMC (19.17 ± 1.18%), WHC (35.69 ± 0.09%), and BD (1.28 ± 0.01 g/cm³) than KK (17.75 ± 0.80%, 31.91%, and 1.32 ± 0.06 g/cm³, respectively) (Table 4.4.1 and Table 4.4.7). At 15-30 cm depth, KG had higher clay (9.23 ± 0.02%) and silt (12.54 ± 0.02%) content, while KK had higher sand content (74.79 ± 0.22%) (Table 4.4.1 and Table 4.4.7). SMC (16.45 ± 0.15%) and WHC (33.54 ± 0.04%) were higher at KG, but BD (1.16 ± 0.01 g/cm³) was lower compared to KK (15.15 ± 0.83%, 30.28 ± 0.03%, and 1.41 ± 0.06 g/cm³, respectively) (Table 4.4.1 and Table 4.4.7).

At 0-15 cm depth, KG had a higher pH (6.48 ± 0.03), SOC (2.71 ± 0.04%), and Avail. N (459.95 ± 27.66 kg/ha), Avail. P (27.21 ± 1.15 kg/ha), Avail. K (168.47 ± 1.17 kg/ha), and Exch. Mg (1.33 ± 0.02 cmol(p^+)/kg) than KK (5.8 ± 0.04, 2.08 ± 0.07%, 156.8 ± 18.11 kg/ha, 21.8 ± 1.11 kg/ha, 144.9 ± 2.68 kg/ha, and 1.34 ± 0.03 cmol(p^+)/kg, respectively (Table 4.4.2 and Table 4.4.8). However, KK had a higher Exch. Na (1.41 ± 0.01 cmol(p^+)/kg) and Exch. Ca (1.81 ± 0.08 cmol(p+)/kg) compared to KG (1.33 ± 0.01 cmol(p^+)/kg and 1.83 ± 0.27 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). At 15-30 cm depth, KG had a higher pH (6.35 ± 0.06), SOC (2.16 ± 0.03%), and Avail. N (407.68 ± 18.11 kg/ha), Avail. P (22.44 ± 0.69 kg/ha), Avail. K (158.8 ± 1.57 kg/ha), and Exch. Mg (1.2 ± 0.06 cmol(p^+)/kg) than KK (5.76 ± 0.04, 0.98 ± 0.07%, 135.89 ± 10.45 kg/ha, 19.77 ± 1.06 kg/ha, 138.28 ± 1.16 kg/ha, and 1.19 ± 0.02 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). However, KK had a higher Exch. Na (1.44 ± 0.01 cmol(p^+)/kg) and Exch. Ca (0.61 ± 0.09 cmol(p^+)/kg) compared to KG (1.35 ± 0.01 cmol(p^+)/kg and 0.63 ± 0.09 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8).

4.4.4.3.1.2. Monsoon Season: At 0-15 cm depth, KG had higher clay (10.54 ± 0.05%) and silt (6.71 ± 0.02%) content, while KK had higher sand content (84.34 ± 0.40%) (Table 4.4.1 and Table 4.4.7). SMC (23.01 ± 0.25%), WHC (43.18 ± 0.12%), and BD (1.12 ± 0.01 g/cm³) were higher at KG compared to KK (22.97 ± 0.54%, 35.93 ± 0.06%, and 1.42 ± 0.01 g/cm³, respectively) (Table 4.4.1 and Table 4.4.7). At 15-30 cm depth, KG had higher clay (14.5 ± 0.06%) and sand (80.68 ± 0.01%) content, while KK had higher silt content (9.06 ± 0.14%). SMC (19.41 ± 0.15%) and WHC (40.17 ± 0.29%) were higher at KG, but BD (1.29 ± 0.01 g/cm³) was lower compared to KK (20.07 ± 0.35%, 33.45 ± 0.37%, and 1.45 ± 0.02 g/cm³, respectively) (Table 4.4.1 and Table 4.4.7).

At 0-15 cm depth, KG had higher pH (5.62 ± 0.05), SOC (2.26 ± 0.03%), and Avail. N (512.21 ± 10.45 kg/ha), Avail. P (35.36 ± 0.84 kg/ha), Avail. K (212.94 ± 2.87 kg/ha), and Exch. Na (1.73 ± 0.01 cmol(p^+)/kg) than KK (5.6 ± 0.04, 1.89 ± 0.09%, 449.49 ± 10.45 kg/ha, 33.61 ± 1.02 kg/ha, 214.25 ± 2.55 kg/ha, and 1.72 ± 0.01 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). However, KK had a higher Exch. Ca (0.9 ± 0.10 cmol(p^+)/kg) compared to KG (0.83 ± 0.12 cmol(p^+)/kg), while exchangeable Mg was higher at KG (1.13 ± 0.06 cmol(p^+)/kg) than KK (1.15 ± 0.02 cmol(p^+)/kg) (Table 4.4.2 and Table 4.4.8). At 15-30 cm depth, KG had a higher pH (5.55 ± 0.03), SOC (1.8 ± 0.06%), and Avail. N (365.87 ± 10.45 kg/ha), Avail. P (32.77 ± 0.94 kg/ha), Avail. K (166.87 ± 3.62 kg/ha), and Exch. Na (1.74 ± 0.01 cmol(p^+)/kg) and Exch. Mg (1.41 ± 0.02 cmol(p^+)/kg) than KK (5.54 ± 0.03, 0.76 ± 0.10%, 321.51 ± 19.76 kg/ha, 25.46 ± 0.82 kg/ha, 211.57 ± 1.77 kg/ha, 1.75 ± 0.01 cmol(p^+)/kg, and 1.26 ± 0.02 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). However, KK had a higher Exch. Ca (1.12 ± 0.07 cmol(p^+)/kg) compared to KG (1.27 ± 0.09 cmol(p^+)/kg) (Table 4.4.2 and Table 4.4.8).

4.4.4.3.1.3. Post monsoon Season: At 0-15 cm depth, KG had higher clay (19.82 ± 0.06%) and silt (4.8 ± 0.05%) content, while KK had higher sand content (63.56 ± 0.04%). SMC (17.8 ± 0.23%) and BD (1.19 ± 0.01 g/cm³) were higher at KG, but WHC (38.13 ± 0.06%) was higher at KK compared to KG (40.67 ± 0.07%) (Table 4.4.1 and Table 4.4.7). At 15-30 cm depth, KG had higher clay (13.89 ± 0.25%) and sand (74.85 ± 0.03%) content, while KK had higher silt content (21.59 ±

0.18%). SMC (16.84 ± 0.53%) and BD (1.22 ± 0.01 g/cm³) were higher at KG, but WHC (37.48 ± 0.03%) was higher at KK compared to KG (38.44 ± 0.06%) (Table 4.4.1 and Table 4.4.7).

At 0-15 cm depth, KG had a higher pH (6.42 ± 0.02), SOC (2.46 ± 0.04%), Avail. N (491.31 ± 10.45 kg/ha), Avail. P (30.22 ± 0.96 kg/ha), Avail. K (181.29 ± 1.99 kg/ha), Exch. Na (1.72 ± 0.01 cmol(p^+)/kg), and Exch. Ca (1.63 ± 0.09 cmol(p^+)/kg) than KK (5.63 ± 0.04, 1.96 ± 0.06%, 240.43 ± 27.66 kg/ha, 26.61 ± 0.42 kg/ha, 182.14 ± 2.01 kg/ha, 1.7 ± 0.01 cmol(p^+)/kg, and 1.36 ± 0.05 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). However, KK had a higher Exch. Mg (0.95 ± 0.04 cmol(p^+)/kg) compared to KG (0.97 ± 0.03 cmol(p^+)/kg) (Table 4.4.2 and Table 4.4.8). At 15-30 cm depth, KG had a higher pH (6.27 ± 0.07), SOC (1.95 ± 0.06%), Avail. N (271.79 ± 10.45 kg/ha), Avail. K (153.14 ± 1.10 kg/ha), Exch. Na (1.76 ± 0.01 cmol(p^+)/kg), and Exch. Mg (1.6 ± 0.03 cmol(p^+)/kg) than KK (5.59 ± 0.01, 0.85 ± 0.08%, 229.97 ± 20.91 kg/ha, 175.9 ± 1.89 kg/ha, 1.74 ± 0.01 cmol(p^+)/kg, and 1.49 ± 0.02 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8). However, KK has a higher average value. P (21.78 ± 0.0 kg/ha) and Exch. Ca (0.89 ± 0.04 cmol(p^+)/kg) compared to KG (25.78 ± 0.71 kg/ha and 1.13 ± 0.15 cmol(p^+)/kg, respectively) (Table 4.4.2 and Table 4.4.8).

Comparative analysis revealed that the soil properties varied between the two sites across different seasons and depths. While KG generally had higher clay, silt, SMC, WHC, and most chemical properties (pH, SOC, available N, P, K, and exchangeable Na and Mg), KK had a higher sand content and Exch. Ca in some cases. These differences could be attributed to various factors, including the parent material, vegetation cover, and management practices at the respective sites.

4.4.4.3.2. Site EP and Site NE (500-1000 m)

4.4.4.3.2.1. Pre-monsoon Season: At 0-15 cm depth, NE had higher sand (79.77 ± 0.18%), clay (6.92 ± 0.11%), SMC (24.51 ± 0.91%), and WHC (36.27 ± 0.01%) content compared to EP (71.06 ± 0.30% sand, 2.28 ± 0.08% clay, 21.11 ± 0.23% SMC, and 36.39 ± 0.01% WHC) (Table 4.4.3 and Table 4.4.9). However, EP had higher silt content (26.66 ± 0.29%) and BD (1.14 ± 0.01 g/cm³) than NE (13.31 ± 0.29% silt and 1.13 ± 0.04 g/cm³ BD) (Table 4.4.3 and Table 4.4.9). At 15-30 cm depth, NE had higher sand (79.89 ± 0.10%), silt (14.42 ± 0.11%), and clay (5.69 ± 0.16%) content, as well as SMC (22.79 ± 0.72%) and WHC (32.49 ± 0.03%), compared to EP (69.15 ± 0.16% sand, 28.4 ± 0.17% silt, 2.45 ± 0.06% clay, 19.23 ± 0.39% SMC, and 32.33 ± 0.10% WHC) (Table 4.4.3 and Table 4.4.9). However, EP had a higher BD (1.30 ± 0.01 g/cm³) than NE (1.15 ± 0.03 g/cm³) (Table 4.4.3 and Table 4.4.9).

At 0-15 cm depth, NE had a higher pH (6.21 ± 0.02), SOC (2.88 ± 0.20%), and Avail. N (397.23 ± 37.69 kg/ha), and Exch. Ca (1.72 ± 0.03 cmol(p^+)/kg) and Exch. Mg (1.55 ± 0.04 cmol(p^+)/kg) compared to EP (5.9 ± 0.01 pH, 2.22 ± 0.08% SOC, 313.6 ± 18.11 kg/ha Avail. N, 1.88 ± 0.03 cmol(p^+)/kg Exch. Ca, and 1.57 ± 0.05 cmol(p^+)/kg Exch. Mg) (Table 4.4.4 and Table 4.4.10). However, EP had a higher Avail. P (21.66 ± 0.38 kg/ha), Avail. K (249.82 ± 1.58 kg/ha), and Exch. Na (1.41 ± 0.03 cmol(p^+)/kg) than NE (19.85 ± 0.76 kg/ha Avail. P, 239.57 ± 1.89 kg/ha Avail. K, and 1.32 ± 0.02 cmol(p^+)/kg Exch. Na) (Table 4.4.4 and Table 4.4.10). At 15-30 cm depth, NE had a higher pH (5.85 ± 0.03), Avail. N (344.96 ± 18.11 kg/ha), and Exch. Na (1.35 ± 0.01 cmol(p^+)/kg) compared to EP (5.7 ± 0.01 pH, 271.79 ± 10.45 kg/ha Avail. N, and 1.49 ± 0.02 cmol(p^+)/kg Exch. Na) (Table 4.4.4 and Table 4.4.10). However, EP had a higher SOC (2.07 ± 0.07%), Avail. P (19.44 ± 1.26 kg/ha), Avail. K (242.74 ± 3.52 kg/ha), Exch. Ca (0.53 ± 0.13 cmol(p^+)/kg), and Exch. Mg (1.33 ± 0.04 cmol(p^+)/kg) compared to NE (2.12 ± 0.04% SOC, 18.1 ± 0.48 kg/ha Avail. P, 232.03 ± 2.12 kg/ha Avail. K, 0.71 ± 0.02 cmol(p^+)/kg Exch. Ca, and 1.27 ± 0.05 cmol(p^+)/kg Exch. Mg) (Table 4.4.4 and Table 4.4.10).

4.4.4.3.2.2. Monsoon Season: At 0-15 cm depth, NE had higher clay (12.29 ± 0.14%), SMC (28.89 ± 0.78%), and WHC (39.11 ± 0.23%) content compared to EP (9.99 ± 0.07% clay, 24.62 ± 0.33% SMC, and 40.31 ± 0.25% WHC) (Table 4.4.3 and Table 4.4.9). However, EP had higher sand (84.74 ± 0.03%) and silt (5.27 ± 0.04%) content, as well as a higher BD (1.24 ± 0.10 g/cm³) than NE (81.16 ± 0.02% sand, 6.55 ± 0.12% silt, and 1.19 ± 0.02 g/cm³ BD) (Table 4.4.3 and Table 4.4.9). At 15-30 cm depth, EP had higher sand (86.17 ± 0.04%), clay (11.5 ± 0.05%), SMC (21.43 ± 0.66%), and WHC (36.43 ± 0.13%) content compared to NE (86.09 ± 0.12% sand, 9.55 ± 0.06% clay, 23.08 ± 0.66% SMC, and 37.99 ± 0.20% WHC) (Table 4.4.3 and

Table 4.4.9). However, NE had higher silt content (4.36 ± 0.08%) and a lower BD (1.21 ± 0.02 g/cm^3) than EP (2.33 ± 0.02% silt and 1.25 ± 0.01 g/cm^3 BD) (Table 4.4.3 and Table 4.4.9).

At 0-15 cm depth, NE had a higher pH (5.57 ± 0.02), Avail. N (501.76 ± 18.11 kg/ha), Avail. K (248.14 ± 3.39 kg/ha), and Exch. Na (1.74 ± 0.01 $cmol(p^+)/kg$) compared to EP (5.62 ± 0.05 pH, 303.15 ± 27.66 kg/ha Avail. N, 262.12 ± 2.26 kg/ha Avail. K, and 1.78 ± 0.01 $cmol(p^+)/kg$ Exch. Na) (Table 4.4.4 and Table 4.4.10). However, EP had a higher SOC (1.78 ± 0.07%) than Avail. P (31.19 ± 1.0 kg/ha), Exch. Ca (0.67 ± 0.07 $cmol(p^+)/kg$), and Exch. Mg (1.33 ± 0.11 $cmol(p^+)/kg$) compared to NE (2.29 ± 0.10% SOC, 27.15 ± 1.51 kg/ha Avail. P, 1.0 ± 0.02 $cmol(p^+)/kg$ Exch. Ca, and 1.27 ± 0.03 $cmol(p^+)/kg$ Exch. Mg) (Table 4.4.4 and Table 4.4.10). At 15-30 cm depth, NE had a higher pH (5.48 ± 0.03), Avail. N (428.59 ± 10.45 kg/ha), Avail. P (25.02 ± 0.62 kg/ha), Avail. K (243.76 ± 3.32 kg/ha), and Exch. Ca (1.34 ± 0.01 $cmol(p^+)/kg$) and Exch. Mg (1.41 ± 0.04 $cmol(p^+)/kg$) compared to EP (5.61 ± 0.02 pH, 261.33 ± 10.45 kg/ha Avail. N, 24.63 ± 0.91 kg/ha Avail. P, 257.2 ± 1.53 kg/ha Avail. K, 0.93 ± 0.02 $cmol(p^+)/kg$ Exch. Ca, and 1.43 ± 0.03 $cmol(p^+)/kg$ Exch. Mg) (Table 4.4.4 and Table 4.4.10). However, EP had a higher Exch. Na (1.72 ± 0.02 $cmol(p^+)/kg$) than NE (1.7 ± 0.01 $cmol(p^+)/kg$) (Table 4.4.4 and Table 4.4.10).

4.4.4.3.2.2. Post monsoon Season: At 0-15 cm depth, NE had higher sand (80.27 ± 0.19%), SMC (20.23 ± 0.73%), and WHC (40.14 ± 0.04%) content compared to EP (75.82 ± 0.05% sand, 20.57 ± 0.42% SMC, and 38.38 ± 0.12% WHC) (Table 4.4.3 and Table 4.4.9). However, EP had higher clay (19.54 ± 0.09%) and silt (4.65 ± 0.04%) content, as well as a higher BD (1.18 ± 0.01 g/cm^3) than NE (5.5 ± 0.12% clay, 14.23 ± 0.08% silt, and 1.16 ± 0.02 g/cm^3 BD) (Table 4.2.3 and Table 4.2.9). At 15-30 cm depth, EP had higher sand (73.69 ± 0.01%), clay (10.84 ± 0.31%), SMC (18.84 ± 0.84%), and WHC (36.88 ± 0.04%) content compared to NE (78.45 ± 0.07% sand, 3.68 ± 0.06% clay, 18.88 ± 0.05% SMC, and 39.41 ± 0.06% WHC) (Table 4.4.3 and Table 4.4.9). However, NE had higher silt content (17.87 ± 0.02%) and a lower BD (1.17 ± 0.02 g/cm^3) than EP (15.48 ± 0.31% silt and 1.33 ± 0.01 g/cm^3 BD) (Table 4.4.3 and Table 4.4.9).

At 0-15 cm depth, NE had a higher pH (5.97 ± 0.07), Avail. N (376.32 ± 18.11 kg/ha), Avail. K (242.41 ± 2.2 kg/ha), Exch. Mg (1.68 ± 0.03 cmol(p^+)/kg), and Exch. Na (1.73 ± 0.02 cmol(p^+)/kg) compared to EP (5.71 ± 0.02 pH, 428.59 ± 10.45 kg/ha Avail. N, 253.12 ± 1.91 kg/ha Avail. K, 1.03 ± 0.12 cmol(p^+)/kg Exch. Mg, and 1.74 ± 0.02 cmol(p^+)/kg Exch. Na) (Table 4.4.4 and Table 4.4.10). However, EP had a higher SOC (2.11 ± 0.03%), Avail. P (23.91 ± 1.06 kg/ha), and Exch. Ca (1.76 ± 0.04 cmol(p^+)/kg) compared to NE (2.66 ± 0.06% SOC, 24.72 ± 0.41 kg/ha Avail. P, and 1.43 ± 0.03 cmol(p^+)/kg Exch. Ca) (Table 4.4.4 and Table 4.4.10). At 15-30 cm depth, NE had a higher pH (5.66 ± 0.03), Avail. N (219.52 ± 36.21 kg/ha), Avail. K (235.65 ± 2.22 kg/ha), Exch. Na (1.74 ± 0.04 cmol(p^+)/kg), and Exch. Mg (1.49 ± 0.02 cmol(p^+)/kg) compared to EP (5.64 ± 0.06 pH, 386.77 ± 10.45 kg/ha Avail. N, 249.29 ± 1.46 kg/ha Avail. K, 1.79 ± 0.04 cmol(p^+)/kg Exch. Na, and 1.66 ± 0.04 cmol(p^+)/kg Exch. Mg) (Table 4.4.4 and Table 4.4.10). However, EP had a higher SOC (1.95 ± 0.04%), Avail. P (20.4 ± 0.64 kg/ha), and Exch. Ca (0.84 ± 0.05 cmol(p^+)/kg) compared to NE (1.25 ± 0.03% SOC, 23.06 ± 0.23 kg/ha Avail. P, and 0.84 ± 0.01 cmol(p^+)/kg Exch. Ca) (Table 4.4.4 and Table 4.4.10).

Comparative analysis revealed that the soil properties varied between sites EP and NE across different seasons and depths. NE generally had higher sand, clay, SMC, WHC, pH, and Avail. N content and EP had higher levels of silt, BD, SOC, Avail. P and Avail. K, and exchangeable cations (Na, Ca, and Mg).

4.4.4.3.3. Site HK and Site KB (<1000 m)

4.4.4.3.3.1. Pre-monsoon Season: At 0-15 cm depth, HK had higher sand (81.41 ± 0.04%) and clay (4.64 ± 0.07%) content, while KB had higher silt content (18.13 ± 0.03%) (Table 4.4.5 and Table 4.4.11). SMC was higher in KB (24.51 ± 1.03%) than in HK (22.06 ± 1.02%), and WHC was also higher in KB (38.02 ± 1.04%) than in HK (36.27 ± 0.01%). However, BD was lower at KB (0.89 ± 0.01 g/cm^3) compared to HK (1.13 ± 0.04 g/cm^3) (Table 4.4.5 and Table 4.4.11). At 15-30 cm depth, HK had a higher sand (80.45 ± 0.05%) content, whereas KB had higher silt (19.68 ± 0.06%) and lower clay (1.73 ± 0.03%) contents. SMC (18.22 ± 0.78%) and WHC (35.30 ± 0.99%) were lower at KB, and BD was also lower (0.98 ± 0.02

g/cm³) compared to HK (23.45 ± 0.54% SMC, 33.77 ± 0.05% WHC, and 1.18 ± 0.01 g/cm³ BD) (Table 4.4.5 and Table 4.4.11).

At 0-15 cm depth, HK had a higher pH (6.41 ± 0.04) and SOC (3.03 ± 0.13%) compared to KB (6.18 ± 0.01 pH, 2.92 ± 0.04% SOC). However, KB had a higher Avail. N (439.04 ± 18.11 kg/ha), Avail. P (25.31 ± 1.07 kg/ha), Exch. Na (1.46 ± 0.01 cmol(p^+)/kg), and Exch. Ca (1.97 ± 0.03 cmol(p^+)/kg) compared to HK (324.05 ± 10.45 kg/ha Avail. N, 29.05 ± 0.76 kg/ha Avail. P, 1.37 ± 0.01 cmol(p+)/kg Exch. Na, and 1.91 ± 0.07 cmol(p^+)/kg Exch. Ca). Avail. K was lower in KB (216.49 ± 2.26 kg/ha) than in HK (237.6 ± 1.82 kg/ha). KB had a slightly lower Exch. Mg (1.34 ± 0.01 cmol(p^+)/kg) compared to HK (1.36 ± 0.03 cmol(p^+)/kg) (Table 4.4.6 and Table 4.4.12). At 15-30 cm depth, HK had a higher pH (6.26 ± 0.18) and SOC (2.69 ± 0.10%) than KB (5.93 ± 0.08 pH, 2.61 ± 0.12% SOC). KB had higher Avail. N (505.23 ± 42.29 kg/ha), Avail. P (30.12 ± 1.62 kg/ha), Avail. K (225.04 ± 2.64 kg/ha), Exch. Na (1.63 ± 0.04 cmol(p^+)/kg), Exch. Ca (1.61 ± 0.11 cmol(p^+)/kg), and Exch. Mg (1.15 ± 0.06 cmol(p^+)/kg) compared to HK (219.52 ± 18.11 kg/ha Avail. N, 22.44 ± 0.50 kg/ha Avail. P, 231.4 ± 1.65 kg/ha Avail. K, 1.39 ± 0.02 cmol(p^+)/kg Exch. Na, 0.7 ± 0.07 cmol(p^+)/kg Exch. Ca, and 1.18 ± 0.02 cmol(p^+)/kg Exch. Mg) (Table 4.4.6 and Table 4.4.12).

4.4.4.3.3.2. Monsoon Season: At 0-15 cm depth, HK had higher sand (85.71 ± 0.01%) content, while KB had higher silt (4.19 ± 0.02%) and clay content (9.10 ± 0.03%) (Table 4.4.5 and Table 4.4.11). SMC was higher in KB (28.54 ± 0.50%) than in HK (24.04 ± 0.71%), and WHC was also higher in KB (44.71 ± 0.75%) than in HK (41.99 ± 0.14%). BD was lower at KB (1.05 ± 0.04 g/cm³) compared to HK (1.19 ± 0.02 g/cm³) (Table 4.4.5 and Table 4.4.11). At 15-30 cm depth, KB had a higher sand (90.86 ± 0.14%), while HK had a higher clay (7.61 ± 0.02%). KB had lower silt content (2.10 ± 0.07%). SMC (20.68 ± 0.33%) was lower in KB, but WHC (38 ± 0.13%) was higher than that in HK (25.4 ± 0.37% SMC and 36.33 ± 0.37% WHC). BD was lower at KB (1.15 ± 0.01 g/cm³) compared to HK (1.2 ± 0.01 g/cm³) (Table 4.4.5 and Table 4.4.11).

At 0-15 cm depth, HK had a slightly higher pH (5.66 ± 0.03) than KB (5.65 ± 0.04). KB had lower SOC (2.31 ± 0.03%), Avail. P (35.75 ± 1.16 kg/ha), and Avail. K

(233.09 ± 2.42 kg/ha) compared to HK (2.67 ± 0.04% SOC, 38.1 ± 2.86 kg/ha Avail. P, 263.68 ± 1.76 kg/ha Avail. K). However, KB had a higher Avail. N (669.01 ± 20.91 kg/ha), Exch. Na (1.70 ± 0.01 cmol(p^+)/kg), and Exch. Ca (1.24 ± 0.06 cmol(p^+)/kg) compared to HK (449.49 ± 10.45 kg/ha Avail. N, 1.63 ± 0.12 cmol(p^+)/kg Exch. Na, and 1.13 ± 0.02 cmol(p^+)/kg Exch. Ca). KB had a slightly lower Exch. Mg (1.14 ± 0.04 cmol(p+)/kg) compared to HK (1.15 ± 0.02 cmol(p^+)/kg) (Table 4.4.6 and Table 4.4.12). At 15-30 cm depth, KB had higher pH (5.84 ± 0.01), SOC (2.66 ± 0.02%), and Avail. N (250.88 ± 18.11 kg/ha) compared to HK (5.57 ± 0.57 pH, 2.34 ± 0.02% SOC, 334.51 ± 10.45 kg/ha Avail. N). However, KB had a lower Avail. P (23.47 ± 0.80 kg/ha), Avail. K (201.83 ± 1.35 kg/ha), Exch. Na (1.40 ± 0.01 cmol(p^+)/kg), Exch. Ca (0.83 ± 0.02 cmol(p^+)/kg), and Exch. Mg (1.16 ± 0.03 cmol(p^+)/kg) compared to HK (34.13 ± 0.73 kg/ha Avail. P, 245.62 ± 2.47 kg/ha Avail. K, 1.73 ± 0.01 cmol(p^+)/kg Exch. Na, 1.35 ± 0.07 cmol(p^+)/kg Exch. Ca, and 1.27 ± 0.02 cmol(p^+)/kg Exch. Mg) (Table 4.4.6 and Table 4.4.12).

4.4.4.3.3.3 Post monsoon Season: At 0-15 cm depth, HK had higher sand (63.17 ± 0.03%) content, while KB had higher silt (23.11 ± 0.11%) and clay (5.38 ± 0.02%) content (Table 4.4.5 and Table 4.4.11). SMC was higher in KB (24.21 ± 1.27%) than in HK (21.52 ± 0.36%), and WHC was also higher in KB (40.38 ± 0.27%) than in HK (40.14 ± 0.04%). BD was slightly lower at KB (0.93 ± 0.02 g/cm³) compared to HK (0.94 ± 0.01 g/cm³) (Table 4.4.5 and Table 4.4.11). At 15-30 cm depth, KB had higher sand (72.21 ± 0.04%) and silt (21.17 ± 0.12%) content, while HK had higher clay (9.26 ± 0.06%) content. SMC (17.90 ± 0.55%) and WHC (38.02 ± 0.10%) were lower at KB, and BD was also lower (1.01 ± 0.01 g/cm³) compared to HK (24.81 ± 0.89% SMC, 40.59 ± 0.12% WHC, and 1.19 ± 0.01 g/cm³ BD) (Table 4.4.5 and Table 4.4.11).

At 0-15 cm depth, HK had a higher pH (6.23 ± 0.04), Avail. N (616.75 ± 10.45 kg/ha), Avail. P (32.26 ± 0.0 kg/ha), and Avail. K (244.08 ± 1.68 kg/ha) compared to KB (5.97 ± 0.09 pH, 407.64 ± 18.14 kg/ha Avail. N, 29.29 ± 1.05 kg/ha Avail. P, and 225.54 ± 1.92 kg/ha Avail. K). However, KB had a slightly lower SOC (2.59 ± 0.29%), higher Exch. Na (1.74 ± 0.02 cmol(p^+)/kg), higher Exch. Ca (1.62 ± 0.03 cmol(p^+)/kg), and slightly higher Exch. Mg (0.97 ± 0.02 cmol(p^+)/kg) compared to HK (2.96 ± 0.08% SOC, 1.69 ± 0.01 cmol(p^+)/kg Exch. Na, 0.97 ± 0.07 cmol(p+)/kg Exch. Ca, and 0.95 ± 0.04 cmol(p^+)/kg Exch. Mg) (Table 4.4.6 and Table 4.4.12). At 15-30 cm depth, HK had a higher pH (6.1 ± 0.12) and SOC (3.53 ± 0.17%) compared to KB (5.59 ± 0.02 pH and 2.26 ± 0.26% SOC). KB had higher Avail. N (637.65 ± 27.66 kg/ha), Avail. P (33.23 ± 0.20 kg/ha), and slightly lower Avail. K (228.56 ± 0.95 kg/ha) compared to HK (533.12 ± 18.11 kg/ha Avail. N, 29.15 ± 0.77 kg/ha Avail. P, and 237.57 ± 2.34 kg/ha Avail. K). KB had slightly lower Exch. Na (1.73 ± 0.01 cmol(p^+)/kg), higher Exch. Ca (1.45 ± 0.02 cmol(p^+)/kg), and lower Exch. Mg (1.26 ± 0.03 cmol(p+)/kg) compared to HK (1.74 ± 0.02 cmol(p^+)/kg Exch. Na, 0.95 ± 0.04 cmol(p^+)/kg Exch. Ca, and 1.37 ± 0.03 cmol(p+)/kg Exch. Mg) (Table 4.4.6 and Table 4.4.12).

Comparative analysis revealed that soil properties varied between sites HK and KB across different seasons and depths.HK generally had higher pH and SOC content, whereas KB showed higher silt content and variable results for other properties depending on the depth and season.

4.5. Plant Growth and Yield Analysis

4.5.1. Maize:

In Churachandpur, at 30 DAS, the mean plant height was higher in KG (62.7 ± 1.72 cm) and HK (63.24 ± 0.82 cm) compared to EP (44.36 ± 0.62 cm) (Table 4.5.1). The mean number of leaves per plant was similar across sites, ranging from 7.2 ± 0.20 to 7.6 ± 0.24 (Table 4.5.1). Leaf area index (LAI) was greatest at KG (0.57 ± 0.01), followed by HK (0.44 ± 0.01) and EP (0.4 ± 0.00) (Table 4.5.1).

By 60 DAS, the HK site exhibited the tallest mean plant height (182.06 ± 1.00 cm), outperforming KG (149.96 ± 15.24 cm) and EP (139.36 ± 3.12 cm) (Table 4.5.1). Mean leaf number per plant increased markedly to 15 ± 0.32 at KG and 15.4 ± 0.24 at HK, while EP lagged at 10.2 ± 0.37 leaves (Table 4.5.1). A substantial increase in LAI was observed, with values of 3.17 ± 0.03, 3.48 ± 0.03, and 2.67 ± 0.02 for KG, HK, and EP respectively (Table 4.5.1).

At 90 DAS, the mean plant heights at KG (239.6 ± 2.15 cm) and HK (240.04 ± 3.20 cm) were similar, while EP (191.04 ± 3.25 cm) was lower (Table 4.5.1). Mean leaf number per plant reached 19.2 ± 0.37 and 19.6 ± 0.24 for KG and HK respectively, with EP at 15.4 ± 0.51 leaves (Table 4.5.1). Peak LAI values were recorded at this stage, with HK achieving 4.64 ± 0.04, followed by KG (4.55 ± 0.04) and EP (3.65 ± 0.05) (Table 4.5.1).

At maturity, the mean plant heights at KG (234.34 ± 2.01 cm) and HK (232.4 ± 3.32 cm) remained higher than EP (188.29 ± 2.87 cm) (Table 4.5.1). Final mean leaf number per plant was 19 ± 0.32, 18.4 ± 0.24, and 13.8 ± 0.37 for KG, HK, and EP respectively (Table 4.5.1). A slight decline in LAI from the 90 DAS values was noted across all sites (Table 4.5.1).

Maize yields were similar across sites, ranging from 816.96 ± 17.10 to 894.72 ± 41.48 kg/ha (Table 4.5.1). However, HK exhibited the highest mean corn weight (141.3 ± 10.29 g) and biomass (368.578 ± 18.26 g), resulting in the highest harvest index of 38.15 ± 0.93% (Table 4.5.1). KG and EP had comparable harvest indexes of 31.64 ± 1.26% and 31.08 ± 1.16% respectively (Table 4.5.1).

In Champhai, at 30 DAS, the mean plant height was higher in KB (66.25 ± 1.24 cm) compared to KK (59.32 ± 0.73 cm) and NE (41.87 ± 0.75 cm) (Table 4.5.2). The mean number of leaves per plant was consistent across sites at 7.4 ± 0.24 to 7.6 ± 0.24 (Table 4.5.2). LAI was highest at KK (0.56 ± 0.01), followed by KB (0.52 ± 0.01) and NE (0.41 ± 0.00) (Table 4.5.2).

By 60 DAS, KK exhibited the tallest mean plant height (193.5 ± 1.66 cm), outperforming KB (174.59 ± 1.63 cm) and NE (140.33 ± 1.36 cm) (Table 4.5.2). Mean leaf number per plant ranged from 12.8 ± 0.20 at NE to 14.2 ± 0.20 at KB (Table 4.5.2). LAI values increased to 2.85 ± 0.04, 2.15 ± 0.05, and 2.77 ± 0.01 for KK, KB, and NE respectively (Table 4.5.2).

At 90 DAS, KK had the highest mean plant height (243.44 ± 5.63 cm), while KB (237.99 ± 3.68 cm) was comparable and NE was notably lower at 202.38 ± 3.57 cm (Table 4.5.2). Mean leaf number per plant was similar across sites, ranging from 17.6 ± 0.24 to 18.6 ± 0.24 (Table 4.5.2). Peak LAI was observed at KK (4.56 ± 0.03), followed by NE (4.38 ± 0.04) and KB (4.32 ± 0.10) (Table 4.5.2).

At maturity, the mean plant heights at KK (238.54 ± 5.60 cm) and KB (230.86 ± 2.24 cm) were higher than NE (197.42 ± 2.96 cm) (Table 4.5.2). Final mean leaf number per plant was consistent across sites at 17.2 ± 0.37 to 17.4 ± 0.40 (Table 4.5.2). LAI values slightly declined from the 90 DAS observations (Table 4.5.2).

Maize yields were highest at KB (886.08 ± 47.95 kg/ha), though not markedly different from KK (851.84 ± 52.47 kg/ha) and NE (826.24 ± 37.27 kg/ha) (Table 4.5.2). KB also had the highest mean corn weight (150.9 ± 5.37 g) and biomass (468.13 ± 10.38 g), but the harvest index was similar across sites, ranging from 0.32 ± 0.01 to 0.37 ± 0.02 (Table 4.5.2). Test weight was comparable across sites, ranging from 202.47 ± 4.49 g to 207.27 ± 8.44 g (Table 4.5.2). The mean number of corns per plant was consistent at 1.6 ± 0.24 (Table 4.5.2).

4.5.2. Cucumber:

In Churachandpur, at 30 DAS, the mean vine length was higher at EP (64.07 ± 3.16 cm) compared to KG (57.38 ± 3.17 cm) and HK (40.22 ± 2.01 cm) (Table 4.5.3). The mean number of leaves per plant ranged from 5.4 ± 0.24 at HK to 9.2 ± 0.37 at KG (Table 4.5.3). LAI was highest at KG (0.91 ± 0.02), followed by EP (0.74 ± 0.02) and HK (0.63 ± 0.02) (Table 4.5.3).

By 60 DAS, KG had the longest mean vine length (252.78 ± 19.56 cm), outperforming EP (177.65 ± 16.04 cm) and HK (116.11 ± 10.66 cm) (Table 4.5.3). Mean leaf number per plant increased to 24.2 ± 0.37 to 28.2 ± 0.37, with LAI values of 2.87 ± 0.10, 2.54 ± 0.02, and 2.39 ± 0.01 for KG, EP, and HK respectively (Table 4.5.3).

At 90 DAS, KG maintained the highest mean vine length (303.42 ± 19.00 cm), higher than EP (256.00 ± 22.05 cm) and HK (181.22 ± 17.00 cm) (Table 4.5.3). Mean leaf number per plant ranged from 28.4 ± 0.24 to 33.8 ± 1.11 (Table 4.5.3). LAI peaked at KG (3.98 ± 0.10), followed by EP (3.56 ± 0.02) and HK (3.34 ± 0.02) (Table 4.5.3).

At maturity, the mean vine length was longest for KG (308.68 ± 18.48 cm) and EP (262.00 ± 22.08 cm), while HK was shortest at 190.34 ± 16.12 cm (Table 4.5.3). Final mean leaf number per plant was highest at KG (37.2 ± 0.97), followed by EP (35.4 ± 1.21) and HK (30 ± 0.45) (Table 4.5.3). Peak LAI values were 4.28 ± 0.07, 3.96 ± 0.02, and 3.68 ± 0.05 for KG, EP, and HK respectively (Table 4.5.3).

Table 4.5.1: Maize growth and yield analysis from jhum fields of Churachandpur

Sites	DAS	Height (cm)	No. of leaves	LAI	Yield (kg/ha)	Corn weight (g)	Biomass (g)	HI (%)
KG	30	62.7 ±1.72	7.6 ±0.24	0.57 ±0.01	893.44 ±87.21	130.65 ±12.91	409.35 ±25.35	31.64 ±1.26
	60	149.96 ±15.24	15 ±0.32	3.17 ±0.03				
	90	239.6 ±2.15	19.2 ±0.37	4.55 ±0.04				
	At maturity	234.34 ±2.01	19 ±0.32	4.25 ±0.04				
EP	30	44.36 ±0.62	7.2 ±0.20	0.4 ±0.00	816.96 ±17.10	118.87 ±8.57	380.42 ±13.72	31.08 ±1.16
	60	139.36 ±3.12	10.2 ±0.37	2.67 ±0.02				
	90	191.04 ±3.25	15.4 ±0.51	3.65 ±0.05				
	At maturity	188.29 ±2.87	13.8 ±0.37	3.29 ±0.07				
HK	30	63.24 ±0.82	7.6 ±0.24	0.44 ±0.01	894.72 ±41.48	141.3 ±10.29	368.578 ±18.26	38.15 ±0.93
	60	182.06 ±1	15.4 ±0.24	3.48 ±0.03				
	90	240.04 ±3.20	19.6 ±0.24	4.64 ±0.04				
	At maturity	232.4 ±3.32	18.4 ±0.24	4.34 ±0.04				

Table 4.5.2: Maize growth and yield analysis from jhum fields of Champhai

Site	DAS	Height (cm)	No. of leaves	LAI	Yield (kg/ha)	Corn weight (g)	Biomass (g)	HI (%)
KK	30	59.32 ±0.73	7.4 ±0.24	0.56 ±0.01	851.84 ±52.47	144.24 ±6.40	429.27 ±13.85	34 ±0.00
	60	193.5 ±1.66	13.8 ±0.37	2.85 ±0.04				
	90	243.44 ±5.63	18.6 ±0.24	4.56 ±0.03				
	At maturity	238.54 ±5.60	17.2 ±0.37	4.27 ±0.04				
NE	30	41.87 ±0.75	7.4 ±0.24	0.41 ±0.00	826.24 ±37.27	139.16 ±9.13	375.11 ±12.55	37 ±0.02
	60	140.33 ±1.36	12.8 ±0.20	2.77 ±0.01				
	90	202.38 ±3.57	17.6 ±0.24	4.38 ±0.04				
	At maturity	197.42 ±2.96	17.4 ±0.40	4.08 ±0.04				
KB	30	66.25 ±1.24	7.6 ±0.24	0.52 ±0.01	886.08 ±47.95	150.9 ±5.37	468.13 ±10.38	32 ±0.01
	60	174.59 ±1.63	14.2 ±0.20	2.15 ±0.05				
	90	237.99 ±3.68	18.4 ±0.93	4.32 ±0.10				
	At maturity	230.86 ±2.24	17.2 ±0.97	3.94 ±0.09				

The mean fruit length was consistent across sites, ranging from 22.99 ± 1.56 23.79 ± 1.90 cm. Individual mean fruit weight was also similar at 310.80 ± 5.48 to 319.77 ± 13.73 g (Table 4.5.3). However, total fruit yield was higher at HK (1400 ± 89.44 kg/ha) compared to KG (1380 ± 96.95 kg/ha) and EP (1200 ± 89.44 kg/ha) (Table 4.5.3). Biomass followed the same pattern, with HK achieving 558.27 ± 2.21 g, KG at 568.54 ± 37.40 g, and EP at 553.52 ± 22.82 g (Table 4.5.3). Harvest index was similar across sites, ranging from 56.41 ± 1.71% to 56.98 ± 1.48% (Table 4.5.3). The number of fruits per plant was consistent across sites, ranging from 2.4 ± 0.24 to 2.8 ± 0.20 (Table 4.5.3).

In Champhai, at 30 DAS, the mean vine length was higher at NE (70.9 ± 2.48 cm) compared to KK (59.66 ± 1.77 cm) and KB (51.26 ± 1.99 cm) (Table 4.5.4). The mean number of leaves per plant ranged from 6.4 ± 0.24 at KB to 8.8 ± 0.20 at KK. LAI was highest at KK (0.9 ± 0.01), followed by NE (0.74 ± 0.01) and KB (0.61 ± 0.02) (Table 4.5.4).

By 60 DAS, KK had the longest mean vine length (207.4 ± 9.82 cm), outperforming KB (199.21 ± 2.53 cm) and NE (173.46 ± 11.88 cm) (Table 4.5.4). Mean leaf number per plant ranged from 23.4 ± 0.24 to 26.4 ± 0.24, with LAI values of 2.73 ± 0.02, 2.39 ± 0.03, and 2.52 ± 0.01 for KK, KB, and NE respectively (Table 4.5.4).

At 90 DAS, KB had the highest mean vine length (312.66 ± 6.80 cm), compared to KK (305.2 ± 14.01 cm) and NE (301.07 ± 4.63 cm) (Table 4.5.4). Mean leaf number per plant ranged from 27.4 ± 0.24 to 31.4 ± 0.40 (Table 4.5.4). Peak LAI was observed at KK (3.8 ± 0.02), followed by NE (3.57 ± 0.01) and KB (3.43 ± 0.04) (Table 4.5.4).

At maturity, the mean vine length was similar across sites, ranging from 308.92 ± 4.60 cm at NE to 316.82 ± 6.51 cm at KB (Table 4.5.4). Final mean leaf number per plant was highest at KK (34.4 ± 0.40), followed by NE (32 ± 0.45) and KB (29.4 ± 0.24) (Table 4.5.4). LAI values were 4.2 ± 0.02, 3.97 ± 0.01, and 3.98 ± 0.05 for KK, NE, and KB respectively (Table 4.5.4).

The mean fruit length and weight were consistent across sites, ranging from 309.16 ± 7.02 to 319.31 ± 5.99 g (Table 4.5.4). Total fruit yield was notably higher at

NE and KB (both 1520 ± 48.99 kg/ha) compared to KK (1120 ± 80.00 kg/ha) (Table 4.5.4). Biomass was similar across sites, ranging from 554.41 ± 10.92 to 563.83 ± 8.40 g (Table 4.5.4). Harvest index was also consistent, with values of 55.86 ± 1.71% to 57.37 ± 0.10% (Table 4.5.4). The number of fruits per plant was consistent across sites at 2.8 ± 0.20 (Table 4.5.4).

Maize growth and yield performance varied across the sites in both Churachandpur and Champhai. In Churachandpur, the KG and HK sites exhibited superior growth characteristics compared with EP, although the final yields were similar. In Champhai, KB exhibited the highest growth and yield, followed by KK and NE. For cucumbers, the KG site in Churachandpur had the most vigorous vegetative growth, whereas HK achieved the highest fruit yield. In Champhai, NE and KB outperformed KK in terms of fruit yield despite similar vegetative growth. These findings suggest that site-specific factors play a significant role in determining the growth and yield of maize and cucumber in the jhum fields of Churachandpur and Champhai.

4.5.3. Comparative analysis of Maize Growth and Yield

4.5.3.1. KG vs KK (<500 m)

At 30 DAS, the mean plant height was similar between KG (62.7 ± 1.72 cm) and KK (59.32 ± 0.73 cm) (Table 4.5.1 and Table 4.5.2). The mean number of leaves per plant and LAI were also comparable. By 60 DAS, KK exhibited a higher mean plant height (193.5 ± 1.66 cm) compared to KG (149.96 ± 15.24 cm), while leaf number (KK: 13.8 ± 0.37; KG: 15 ± 0.32) and LAI (KK: 2.85 ± 0.04; KG: 3.17 ± 0.03) remained similar (Table 4.5.1 and Table 4.5.2). At 90 DAS and maturity, both sites had comparable plant heights, leaf numbers, and LAI values. Maize yields were also similar between KG (893.44 ± 87.21 kg/ha) and KK (851.84 ± 52.47 kg/ha) (Table 4.3.1 and Table 4.3.2). However, KK had a higher biomass (429.27 ± 13.85 g) compared to KG (409.35 ± 25.35 g) (Table 4.5.1 and Table 4.5.2). The harvest index was higher for KG (31.64 ± 1.26%) compared to KK (34 ± 0.00%) (Table 4.5.1 and Table 4.5.2).

Table 4.5.3: Cucumber growth and yield analysis from jhum fields of Churachandpur

Sites	DAS	Vine length (cm)	No. of leaves (cm)	LAI (%)	Length of fruit (cm)	Wt. of fruit (g)	Yield (kg/ha)	Biomass (g)	HI (%)
KG	30	57.38 ±3.17	9.2 ±0.37	0.91 ±0.02	23.79 ±1.90	319.77 ±13.73	1380 ±96.95	568.54 ±37.40	56.60 ±1.37
	60	252.78 ±19.56	28.2 ±0.37	2.87 ±0.10					
	90	303.42 ±19	33.8 ±1.11	3.98 ±0.10					
	At maturity	308.68 ±18.48	37.2 ±0.97	4.28 ±0.07					
EP	30	64.07 ±3.16	9 ±0.32	0.74 ±0.02	22.99 ±1.56	310.80 ±5.48	1200 ±89.44	553.52 ±22.82	56.41 ±1.71
	60	177.65 ±16.04	25.8 ±0.37	2.54 ±0.02					
	90	256 ±22.05	30.6 ±0.24	3.56 ±0.02					
	At maturity	262 ±22.08	35.4 ±1.21	3.96 ±0.02					
HK	30	40.22 ±2.01	5.4 ±0.24	0.63 ±0.02	23.59 ±1.48	318.04 ±7.70	1400 ±89.44	558.27 ±2.21	56.98 ±1.48
	60	116.11 ±10.66	24.2 ±0.37	2.39 ±0.01					
	90	181.22 ±17	28.4 ±0.24	3.34 ±0.02					
	At maturity	190.34 ±16.12	30 ±0.45	3.68 ±0.05					

Table 4.5.4: Cucumber growth and yield analysis from jhum fields of Champhai

Site	DAS	Vine length (cm)	No. of leaves	LAI	Yield (kg/ha)	Fruit weight (g)	Biomass (g)	HI (%)
KK	30	59.66 ±1.77	8.8 ±0.20	0.9 ±0.01	1120 ±80	314.7 ±10.17	563.83 ±8.40	55.93 ±2.42
	60	207.4 ±9.82	26.4 ±0.24	2.73 ±0.02				
	90	305.2 ±14.01	31.4 ±0.40	3.8 ±0.02				
	At maturity	315.42 ±14.13	34.4 ±0.40	4.2 ±0.02				
NE	30	70.9 ±2.48	8.4 ±0.24	0.74 ±0.01	1520 ±48.99	309.16 ±7.02	554.41 ±10.92	55.86 ±1.71
	60	173.46 ±11.88	24.2 ±0.37	2.52 ±0.01				
	90	301.07 ±4.63	29 ±0.45	3.57 ±0.01				
	At maturity	308.92 ±4.60	32 ±0.45	3.97 ±0.01				
KB	30	51.26 ±1.99	6.4 ±0.24	0.61 ±0.02	1520 ±48.99	319.31 ±5.99	556.58 ±10.53	57.37 ±0.10
	60	199.21 ±2.53	23.4 ±0.24	2.39 ±0.03				
	90	312.66 ±6.80	27.4 ±0.24	3.43 ±0.04				
	At maturity	316.82 ±6.51	29.4 ±0.24	3.98 ±0.05				

4.5.3.2. EP vs NE (500-1000 m)

At 30 DAS, NE had a lower mean plant height (41.87 ± 0.75 cm) compared to EP (44.36 ± 0.62 cm), whereas the leaf number and LAI were similar (Table 4.5.1 and Table 4.5.2). By 60 DAS, NE had a comparable mean plant height (140.33 ± 1.36 cm) to EP (139.36 ± 3.12 cm), while leaf number (NE: 12.8 ± 0.20; EP: 10.2 ± 0.37) and LAI (NE: 2.77 ± 0.01; EP: 2.67 ± 0.02) were similar (Table 4.5.1 and Table 4.5.2). At 90 DAS and maturity, both sites had comparable plant heights, leaf numbers, and LAI values. Maize yields were slightly lower in EP (816.96 ± 17.10 kg/ha) compared to NE (826.24 ± 37.27 kg/ha) (Table 4.5.1 and Table 4.5.2). Biomass was slightly higher in EP (380.42 ± 13.72 g) compared to NE (375.11 ± 12.55 g), while the harvest index was higher in NE (37 ± 0.02%) compared to EP (31.08 ± 1.16%) (Table 4.5.1 and Table 4.5.2).

4.5.3.3. HK vs KB (<1000 m)

At 30 DAS, the mean plant height was lower at HK (63.24 ± 0.82 cm) compared to KB (66.25 ± 1.24 cm), whereas the leaf number and LAI were similar (Table 4.5.1 and Table 4.5.2). By 60 DAS, KB had a lower mean plant height (174.59 ± 1.63 cm) compared to HK (182.06 ± 1.00 cm), while leaf number (KB: 14.2 ± 0.20; HK: 15.4 ± 0.24) was slightly lower for KB and LAI (KB: 2.15 ± 0.05; HK: 3.48 ± 0.03) was notably lower for KB (Table 4.5.1 and Table 4.5.2). At 90 DAS and maturity, both sites had comparable plant heights, leaf numbers, and LAI values (Table 4.3.1 and Table 4.3.2). Maize yields were similar between HK (894.72 ± 41.48 kg/ha) and KB (886.08 ± 47.95 kg/ha) (Table 4.5.1 and Table 4.5.2). However, KB had a higher biomass (468.13 ± 10.38 g) compared to HK (368.578 ± 18.26 g) (Table 4.5.1 and Table 4.5.2). The harvest index was higher for HK (38.15 ± 0.93%) compared to KB (32 ± 0.01%) (Table 4.5.1 and Table 4.5.2).

4.5.4. Comparative analysis of Cucumber Growth and Yield

4.5.4.1 KG vs KK (< 500 m)

At 30 DAS, the mean vine length was similar between KG (57.38 ± 3.17 cm) and KK (59.66 ± 1.77 cm) (Table 4.5.3 and Table 4.5.4). Leaf number (KG: 9.2 ± 0.37; KK: 8.8 ± 0.20) and LAI (KG: 0.91 ± 0.02; KK: 0.9 ± 0.01) were also comparable (Table 4.5.3 and Table 4.5.4). By 60 DAS, KG had a higher mean vine length (252.78 ± 19.56 cm) compared to KK (207.4 ± 9.82 cm), while leaf number (KG: 28.2 ± 0.37; KK: 26.4 ± 0.24) and LAI (KG: 2.87 ± 0.10; KK: 2.73 ± 0.02) were similar (Table 4.5.3 and Table 4.5.4). At 90 DAS and maturity, both sites had similar vine lengths, leaf numbers, and LAI values (Table 4.5.3 and Table 4.5.4). However, KG had a higher fruit yield (1380 ± 96.95 kg/ha) compared to KK (1120 ± 80.00 kg/ha) (Table 4.5.3 and Table 4.5.4). Biomass was slightly higher for KG (568.54 ± 37.40 g) compared to KK (563.83 ± 8.40 g), while the harvest index was similar between KG (56.60 ± 1.37%) and KK (55.93 ± 2.42%) (Table 4.5.3 and Table 4.5.4).

4.5.4.2 EP vs NE (500-1000 m)

At 30 DAS, NE had a higher mean vine length (70.9 ± 2.48 cm) compared to EP (64.07 ± 3.16 cm) (Table 4.5.3 and Table 4.5.4). Leaf number (NE: 8.4 ± 0.24; EP: 9 ± 0.32) was slightly lower for NE, while LAI (NE: 0.74 ± 0.01; EP: 0.74 ± 0.02) was similar (Table 4.5.3 and Table 4.5.4). By 60 DAS, NE had a slightly lower mean vine length (173.46 ± 11.88 cm) compared to EP (177.65 ± 16.04 cm), while leaf number (NE: 24.2 ± 0.37; EP: 25.8 ± 0.37) and LAI (NE: 2.52 ± 0.01; EP: 2.54 ± 0.02) were similar (Table 4.5.3 and Table 4.5.4). At 90 DAS and maturity, both sites had comparable vine lengths, leaf numbers, and LAI values (Table 4.5.3 and Table 4.5.4). However, NE had a higher fruit yield (1520 ± 48.99 kg/ha) compared to EP (1200 ± 89.44 kg/ha) (Table 4.3.3 and Table 4.3.4). Biomass was slightly higher for NE (554.41 ± 10.92 g) compared to EP (553.52 ± 22.82 g), while the harvest index was slightly higher for EP (56.41 ± 1.71%) compared to NE (55.86 ± 1.71%) (Table 4.5.3 and Table 4.5.4).

4.5.4.3 HK vs KB (< 1000 m)

At 30 DAS, the mean vine length was lower at HK (40.22 ± 2.01 cm) compared to KB (51.26 ± 1.99 cm) (Table 4.5.3 and Table 4.5.4). Leaf number (HK: 5.4 ± 0.24; KB: 6.4 ± 0.24) was slightly lower for HK, while LAI (HK: 0.63 ± 0.02; KB: 0.61 ± 0.02) was similar (Table 4.5.3 and Table 4.5.4). By 60 DAS, KB had a higher mean vine length (199.21 ± 2.53 cm) compared to HK (116.11 ± 10.66 cm), while leaf number (KB: 23.4 ± 0.24; HK: 24.2 ± 0.37) and LAI (KB: 2.39 ± 0.03; HK: 2.39 ± 0.01) were similar (Table 4.5.3 and Table 4.5.4). At 90 DAS, KB had a higher mean vine length (312.66 ± 6.80 cm) compared to HK (181.22 ± 17.00 cm), while leaf number (KB: 27.4 ± 0.24; HK: 28.4 ± 0.24) and LAI (KB: 3.43 ± 0.04; HK: 3.34 ± 0.02) were similar (Table 4.5.3 and Table 4.5.4). At maturity, KB had a higher mean vine length (316.82 ± 6.51 cm) compared to HK (190.34 ± 16.12 cm), and a slightly lower leaf number (KB: 29.4 ± 0.24; HK: 30 ± 0.45), while LAI (KB: 3.98 ± 0.05; HK: 3.68 ± 0.05) was higher for KB (Table 4.5.3 and Table 4.5.4). Despite the differences in vegetative growth, fruit yield was similar between HK (1400 ± 89.44 kg/ha) and KB (1520 ± 48.99 kg/ha) (Table 4.5.3 and Table 4.5.4). Biomass was slightly higher for HK (558.27 ± 2.21 g) compared to KB (556.58 ± 10.53 g), while the harvest index was slightly higher for KB (57.37 ± 0.10%) compared to HK (56.98 ± 1.48%) (Table 4.5.3 and Table 4.5.4).

Comparison of maize growth and yield between KG and KK, EP and NE, and HK and KB revealed site-specific differences, particularly in the early growth stages. However, these differences did not significantly affect the final maize yield. Biomass and harvest index also showed some site-specific differences, with KG having a higher biomass than KK and KB having a higher biomass than HK. For cucumber, the comparison between KG and KK, and EP and NE showed some differences in vegetative growth, with KG having a higher vine length at 60 DAS than KK, and NE having a higher vine length at 30 DAS but a lower vine length at 60 DAS than EP. Despite these differences, the fruit yield was significantly higher in KG and NE than in their counterparts. The biomass and harvest indices were similar across these sites. A comparison between HK and KB revealed consistent differences in vegetative growth, with KB exhibiting greater vine lengths throughout the growth stages.

However, these differences did not translate into significant differences in the fruit yield, biomass, or harvest index.

4.6. Economic viability of jhum fields

For maize cultivation at KG, the total input cost was Rs. 12,250, which included the costs for maize seeds (Rs. 100), land preparation (Rs. 4,500), sowing and planting (Rs. 1,350), weeding (Rs. 2,250), manuring (Rs. 1,350), and harvesting (Rs. 2,700) with an output value of Rs. 28,120 (Table 4.6.1). The cucumber production at this site had a total input cost of Rs. 13,200, comprising costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,800), weeding (Rs. 2,700), manuring (Rs. 1,800), harvesting (Rs. 3,150), and an output value of Rs.43,100 (Table 4.6.2), making cucumber cultivation more profitable than maize cultivation.

Maize cultivation at EP had a total input cost of Rs. 11,350, including the costs for maize seeds (Rs. 100), land preparation (Rs. 4,500), sowing (Rs. 1,350), weeding (Rs. 2,250), manuring (Rs. 900), and harvesting (Rs. 2,250), with an output value of Rs. 23,774 (Table 4.6.3). The cucumber production at this site had a total input cost of Rs. 13,650, comprising costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,350), weeding (Rs. 3,150), manuring (Rs. 1,800), harvesting (Rs. 3,600), and an output value of Rs. 43,200 (Table 4.6.4).

In HK, maize cultivation had a total input cost of Rs. 12,250, including costs for maize seeds (Rs. 100), land preparation (Rs. 4,500), sowing and planting (Rs. 1,800), weeding (Rs. 2,250), manuring (Rs. 900), harvesting (Rs. 2,700), and an output value of Rs. 28,260 (Table 4.6.5). Cucumber production at this site had a total input cost of Rs. 12,750, comprising costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,350), weeding (Rs. 2,250), manuring (Rs. 1,800), and harvesting (Rs. 3,600). With an output value was Rs. 42,000, cucumber cultivation is more profitable than maize (Table 4.6.6).

The total input cost for maize cultivation at KK was Rs. 12,700, which included the costs for maize seeds (Rs. 100), land preparation (Rs. 4,500), sowing and planting (Rs. 1,350), weeding (Rs. 2,250), manuring (Rs. 1,800), and harvesting (Rs. 2,700), with an output value of Rs. 28,847 (Table 4.6.7). Cucumber production at this site had a total input cost of Rs. 14,550, which was the highest among the cucumber sites, including costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,800), weeding (Rs. 3,150), manuring (Rs. 2,250), and harvesting (Rs. 3,600). With an output value was Rs. 44,400, making it the highest among the sites for cucumber and still higher than maize cultivation (Table 4.6.8).

Table 4.6.1: Input-output analysis for maize at site KG

Input costs	Rate	Days	**Input (I)**	**Output (O)** Maize @50/kg	**Profit (O-I)**
Maize seed @100/kg	100		100	**28,120**	**15,870**
Land preparation @450/ days	450	10	4500		
Sowing and planting @450/days	450	3	1350		
Weeding @450/day	450	5	2250		
Manuring @450/day	450	3	1350		
Harvesting @450/day	450	6	2700		
Total			**12,250**	**28,120**	**15,870**

Table: 4.6.2: Input-output analysis for cucumber at site KG

Input costs	Rate	Days	**Input (I)**	**Output (O)** Cucumber @100/kg	**Profit (O-I)**
Cucumber seed @300/kg	300/kg		150	**43,100**	**30,200**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/days	450	4	1800		
Weeding @450/day	450	6	2700		
Manuring @450/day	450	4	1800		
Harvesting @450/day	450	7	3150		
Total			**13,200**	**43,100**	**30,200**

Table: 4.6.3: Input-output analysis for maize at site EP

Input costs	Rate	Days	**Input (I)**	**Output (O)** Maize @50/kg	**Profit (O-I)**
Maize seed	100/kg		100	**23,774**	**29,550**
Land preparation	450	10	4500		
Sowing	450	3	1350		
Weeding	450	5	2250		
Manuring	450	2	900		
Harvesting @450/day	450	5	2250		
Total		.	**11,350**	**23,774**	**29,550**

Table 4.6.4: Input-output analysis for cucumber at site EP

Input costs	Rate	Days	**Input (I)**	**Output (O)** Cucumber @100/kg	**Profit (O-I)**
Cucumber seed @300/kg			150	**43,200**	**29,550**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/days	450	3	1350		
Weeding @450/day	450	7	3150		
Manuring @450/day	450	4	1800		
Harvesting @450/day	450	8	3600		
Total			**13,650**	**43,200**	**29,550**

Table 4.6.5: Input-output analysis for maize at site HK

Input costs	Rate	Days	Input (I)	Output (O)	Profit
				Maize @50/kg	(O-I)
Maize seed @100/kg	100		100	**28,260**	**16,010**
Land preparation @450/ days	450	10	4500		
Sowing and planting @450/days	450	4	1800		
Weeding @450/day	450	5	2250		
Manuring @450/day	450	2	900		
Harvesting @450/day	450	6	2700		
Total		.	**12,250**	**28,260**	**16,010**

Table 4.6.6: Input-output analysis for cucumber at site HK

Input costs	Rate	Days	Input (I)	Output (O)	Profit (O-I)
				Cucumber @100/kg	
Cucumber seed @300/kg			150	**42,000**	**29,250**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/days	450	3	1350		
Weeding @450/day	450	5	2250		
Manuring @450/day	450	4	1800		
Harvesting @450/day	450	8	3600		
Total			**12,750**	**42,000**	**29,250**

Table 4.6.7: Input-output analysis for maize at site KK

Input costs	Rate	Days	Input (I)	Output (O) Maize @50/kg	Profit (O-I)
Maize seed @100/kg	100		100	**28,847**	**16,147**
Land preparation @450/ days	450	10	4500		
Sowing and planting @450/ days	450	3	1350		
Weeding @450/ days	450	5	2250		
Manuring@450/ days	450	4	1800		
Harvesting @450/ days	450	6	2700		
Total			**12,700**	**28,847**	**16,147**

Table 4.6.8: Input-output analysis of cucumber for site KK

Input costs	Rate	Days	Input (I)	Output (O) Cucumber @100/kg	Profit (O-I)
Seed @300/kg	300		150	**44,400**	**29,850**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/ days	450	4	1800		
Weeding @450/ days	450	7	3150		
Manuring @450/ days	450	5	2250		
Harvesting @450/ days	450	8	3600		
Total			**14,550**	**44,400**	**29,850**

Table 4.6.9: Input-output analysis of maize for site NE

Input costs	Rate	Days	Input (I)	Output (O)	Profit
				Maize @50/kg	(O-I)
Maize seed @100/kg	100		100	**27,831**	**15,581**
Land preparation @450/ days	450	10	4500		
Sowing and planting @450/ days	450	3	1350		
Weeding @450/ days	450	4	1800		
Manuring @450/ days	450	4	1800		
Harvesting @450/ days	450	6	2700		
Total			**12,250**	**27,831**	**15,581**

Table 4.6.10: Input-output analysis of cucumber for site NE

Input costs	Rate	Days	Input (I)	Output (O)	Profit (O-I)
				Cucumber @100/kg	
Cucumber seed @300/kg	300		150	**45,600**	**31,500**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/ days	450	3	1350		
Weeding @450/ days	450	7	3150		
Manuring @450/ days	450	5	2250		
Harvesting @450/ days	450	8	3600		
Total			**14,100**	**45,600**	

Table 4.6.11: Input-output analysis for maize at site KB

Input costs	Rate	Days	**Input (I)**	**Output (O)** Maize @50/kg	**Profit (O-I)**
Maize seed	100/kg		100	**30,180**	**17,480**
Land preparation @450/ days	450	10	4500		
Sowing and planting @450/ days	450	4	1800		
Weeding @450/ days	450	4	1800		
Manuring @450/ days	450	4	1800		
Harvesting @450/ days	450	6	2700		
Total			**12,700**	**30,180**	**17,480**

Table 4.6.12: Input-output analysis for cucumber at site KB

Input costs	Rate	Days	**Input (I)**	**Output (O)** Cucumber @100/kg	**Profit (O-I)**
Cucumber seed	300/kg		150	**44,600**	**31,400**
Land preparation @450/ days	450	8	3600		
Sowing and planting @450/ days	450	3	1350		
Weeding @450/ days	450	5	2250		
Manuring @450/ days	450	5	2250		
Harvesting @450/ days	450	8	3600		
Total			**13,200**	**44,600**	**31,400**

Maize cultivation in NE had a total input cost of Rs. 12,250, including costs for maize seeds (Rs. 100), land preparation (Rs. 4,500), sowing and planting (Rs. 1,350), weeding (Rs. 1,800), manuring (Rs. 1,800), and harvesting (Rs. 2,700) with an output value of Rs. 27,831 (Table 4.6.9). Cucumber production at this site had a total input cost of Rs. 14,100, comprising costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,350), weeding (Rs. 3,150), manuring (Rs. 2,250), and harvesting (Rs. 3,600). The output value was Rs. 45,600, indicating greater profitability than maize farming (Table 4.6.10).

At KB, maize cultivation had a total input cost of Rs. 12,700, including costs for maize seed (Rs. 100), land preparation (Rs. 4,500), sowing and planting (Rs. 1,800), weeding (Rs. 1,800), manuring (Rs. 1,800), and harvesting (Rs. 2,700) and the output value was the highest among the sites at Rs. 30,180 (Table 4.6.11). Cucumber production at this site had an output of Rs. 44,600, with a total input cost of Rs. 13,200, comprising the costs for cucumber seeds (Rs. 150), land preparation (Rs. 3,600), sowing and planting (Rs. 1,350), weeding (Rs. 2,250), manuring (Rs. 2,250), and harvesting (Rs. 3,600) (Table 4.6.12).

4.6.1. Cost Benefit Analysis

The significance of conducting Benefit-Cost Analysis (BCA) lies in its capacity to provide a systematic and objective assessment of the economic feasibility of a project or investment. BCA assists decision-makers in allocating resources efficiently by comparing the anticipated benefits and costs of various alternatives (Boardman et al., 2018).In the context of agricultural production, BCA is essential for farmers to evaluate the profitability of different crops and make well-informed decisions regarding resource allocation and crop selection (Lazarus, 2014).

Table 4.6.13: Benefit cost Ratio of maize of selected jhum fields

Sites	Benefits (Rs.)	Costs (Rs.)	BC Ratio
KG	28,120	12,250	**2.30**
EP	23,774	11,350	**2.09**
HK	28,260	12,250	**2.31**
KK	28,847	12,700	**2.27**
NE	27,831	12,250	**2.27**
KB	30,180	12,700	**2.38**

The Benefit-Cost Ratios (BCRs) for maize in Churachandpur are 2.30 (KG), 2.09 (EP), and 2.31 (HK), while in Champhai, the BCRs are 2.27 (KK), 2.27 (NE), and 2.38 (KB) (Table 4.6.13). The highest BCR for maize is observed in KB (Champhai) at 2.38, while the lowest is in EP (Churachandpur) at 2.09 (Table 4.6.13).

For cucumber production, the benefit-cost ratios (BCRs) were 3.27 for KG, 3.16 for EP, and 3.29 for HK in Churachandpur (Table 4.6.14), while in Champhai, the BCRs were 3.06 for KK, 3.23 for NE, and 3.38 for KB (Table 4.6.14). The higher BCRs for cucumber compared to maize indicate that cucumber production is more lucrative than maize in both Champhai and Churachandpur regions, with KB in Champhai exhibiting the highest BCR of 3.38 for cucumber (Table 4.6.14).

Table 4.6.14: Benefit cost Ratio of cucumber of selected jhum fields

Sites	Benefits (Rs.)	Costs (Rs.)	BC Ratio
KG	43,100	13,200	3.27
EP	43,200	13,650	3.16
HK	42,000	12,750	3.29
KK	44,400	14,500	3.06
NE	45,600	14,100	3.23
KB	44,600	13,200	3.38

Abbreviation: BC Ratio= Benefit Cost Ratio.

Comparing the sites within each region, KB demonstrated the highest BCR for both maize (2.38) and cucumber (3.38) in Champhai, whereas KK had the lowest BCR for both crops (2.27 for maize and 3.06 for cucumber). In Churachandpur, HK exhibited the highest BCR for both maize (2.31) and cucumber (3.29), whereas EP had the lowest BCR for both crops (2.09 for maize and 3.16 for cucumber).

4.6.2. Comparative analysis between Churachandpur and Champhai

4.6.2.1. KG vs KK: For maize, KG (Churachandpur) has a slightly higher BCR of 2.30 compared to KK (Champhai) with a BCR of 2.27 (Table 4.6.13). This indicates that maize production is marginally more profitable in KG than it is in KK. In the case of cucumber, KG has a considerably higher BCR of 3.27 compared to KK's BCR of 3.06 (Table 4.6.14).

4.6.2.2. EP vs NE: In maize production, EP (Churachandpur) has a lower BCR of 2.09 compared to NE (Champhai) with a BCR of 2.27 (Table 4.6.13). This indicates that maize production is more profitable in NE than in EP. For cucumber, EP has a slightly lower BCR of 3.16 compared to NE's BCR of 3.23 (Table 4.6.14).

4.6.2.3. HK vs KB: For maize, HK (Churachandpur) has a BCR of 2.31, which is slightly lower than KB's (Champhai) BCR of 2.38 (Table 4.6.13). This indicates that maize production is marginally more profitable in KB than HK. In the case of cucumber, HK has a BCR of 3.29, which is lower than KB's BCR of 3.38 (Table 4.6.14).

Although the input costs varied across sites, cucumber cultivation consistently yielded higher output values and BCRs than maize cultivation at all sites, with site KB emerging as the most profitable location for both crops.

CHAPTER – 5

DISCUSSION

5.1. Mode of operation

The mode of cultivation observed in the jhum fields of Churachandpur and Champhai districts in Manipur and Mizoram, India, exhibits a high degree of consistency in terms of field size, cultivation practices, and labour requirements. This consistency can be attributed to the shared cultural and ecological context of the region as well as the common challenges faced by jhum cultivators, such as soil erosion and declining soil fertility (Pandey et al., 2022b). Compared with other land uses and agricultural practices in India and the world, jhum cultivation stands out as a unique and traditional farming system. In India, other prevalent agricultural practices include intensive irrigated agriculture, rain-fed agriculture, and agroforestry systems (Bhattacharyya et al., 2015). Irrigated agriculture, prevalent in the Indo-Gangetic plains and other regions with access to irrigation facilities, is characterised by the intensive use of inputs, including fertilisers, pesticides, and improved crop varieties (Velayudhan et al., 2021). Jat et al. (2011) investigated stagnating yield and declining input use efficiency in irrigated wheat of the Indo-Gangetic Plain (IGP) and proposed precision land levelling with raised bed planting as a potential solution to enhance crop yield, water, and nutrient use efficiency. The application of fertilisers in this context was further explored by Kakraliya et al. (2017), who examined the combined effect of organic and inorganic fertilisers on the grain yield, fertiliser use efficiency, and grain quality of wheat crops in the Indo-Gangetic Plains. Kumar et al. (2017) addressed the challenges of weed control in zero-till rice–wheat cropping systems of the Indo-Gangetic Plains, highlighting the increased reliance on herbicides. Bhatt et al. (2021) discussed the rapid adoption of high-yielding cultivars of rice and wheat in the Indo-Gangetic Plains, underscoring the significance of improved crop varieties in this region.

Rain-fed agriculture, which is practiced in regions with limited access to irrigation, shares some similarities with jhum cultivation in terms of its reliance on natural rainfall. However, rain-fed agriculture often involves the use of improved crop varieties, fertilisers, and soil and water conservation measures to enhance productivity and sustainability (Venkateswarlu & Prasad, 2012).Agroforestry systems, which integrate trees with crops and/or livestock, are another land-use practice found in various parts of India. These systems aim to optimise the use of land resources, conserve biodiversity, and provide multiple benefits to farmers, such as food, fodder, and fuelwood (Dhyani et al., 2009).

Globally, shifting cultivation systems similar to jhum are practiced in various tropical regions such as Southeast Asia, Africa, and South America (van Vliet et al., 2012).These systems are characterised by the rotation of cultivation and fallow periods, with the fallow phase allowing for the regeneration of soil fertility and vegetation. However, increasing population pressure and the need for agricultural intensification have led to the shortening of fallow periods and the degradation of land resources in many shifting cultivation systems (Mertz et al., 2009). In contrast to intensive agricultural practices in developed countries, which rely heavily on mechanisation, synthetic inputs, and monoculture cropping systems (Tilman et al., 2002), jhum cultivation represents a low-input, diversified farming system that is adapted to local ecological and socio-economic conditions. However, the sustainability of jhum cultivation faces challenges due to increasing population pressure, the need for longer fallow periods, and the lack of proper soil and water conservation measures.

To address these challenges and ensure the sustainability of jhum cultivation, it is essential to develop and promote appropriate land management practices such as agroforestry, contour hedgerow farming, and the use of leguminous cover crops (Mishra et al., 2019). Furthermore, the integration of traditional knowledge with modern scientific approaches can help optimise the productivity and resilience of jhum cultivation systems while preserving the cultural heritage and biodiversity of the region (Parrotta et al., 2015).

5.2. Crop composition

The crop composition in the jhum fields of Churachandpur (KG, EP, and HK) and Champhai (KK, NE, and KB) districts of Mizoram, India, shows a diverse array of plant species from various families. The dominance of crops from Cucurbitaceae and Poaceae families, particularly cucumber (*Cucumis sativus*) and maize (*Zea mays*), across all study sites underscores their significance in the local diet and their adaptability to the jhum cultivation system. The presence of other common crops like beans (*Phaseolus vulgaris* L.), pumpkin (*Cucurbita pepo*), and taro (*Colocasia esculenta*) in most sites further highlights the importance of these crops in the jhum system. The diversity of crops grown in the jhum fields is a testament to the system's role in maintaining agro-biodiversity and ensuring local food security (Mandal & Raman, 2016). The cultivation of a wide range of crops not only provides a varied diet for local communities but also acts as a risk mitigation strategy, as the failure of one crop can be offset by the success of others (Birthal et al., 2021).

Compared to other agricultural systems, the crop composition in jhum fields stands out for its diversity and use of traditional crop varieties. In contrast, modern intensive agricultural systems often focus on monoculture cropping and the use of high-yielding crop varieties, which can lead to a reduction in agrobiodiversity (Cardinale et al., 2012). The traditional knowledge associated with jhum cultivation plays a crucial role in the selection and management of diverse crop species, ensuring their conservation and sustainable use (Parrotta et al., 2015).

Similar to the findings of this study, Payum et al. (2021) recorded 43 plant varieties cultivated by different tribes in the Upper Siang district of Arunachal Pradesh, including cucumber, maize, and chili pepper. Pandey et al. (2022a) and Pandey et al. (2022b) also documented 42 and 41 plant and animal varieties, respectively, from jhum fields in the Upper Subansiri district of Arunachal Pradesh and West Garo Hills of Meghalaya. These studies categorised crops into five food groups: cereals and legumes, vegetables, fruits, spices, and livestock. The similarity in crop composition across these studies highlights the importance of jhum cultivation in preserving agrobiodiversity and supporting local food security in the northeastern region of India.

In other states of Northeast India, such as Nagaland, jhum fields commonly include crops, such as rice, maize, millet, job tears, beans, ginger, chili pepper, and various vegetables (Chase & Singh, 2014). In the jhum fields of Manipur, the Marings cultivate a variety of crops including, cucumbers, soybeans, brinjals, maize, sesame, ginger, sweet potatoes, beans, groundnuts, pumpkins, yams, and coriander (Maring & Pillai, 2023). Shifting cultivation is also practiced in other Indian states, such as Odisha, where crops such as rice, finger millet, black gram, pigeon peas, and various vegetables are grown (Dash & Misra, 2001).

In neighbouring countries, such as Bangladesh, crops grown in jhum cultivation include rice, maize, sesame, cotton, cucumbers, and beans (Rahman et al., 2017).In Nepal, shifting cultivation, called 'khoriya', involves growing crops like maize, millet, buckwheat, soybean, and various vegetables (Khadka et al., 2021).Shifting cultivation in China, particularly in Yunnan Province, includes crops such as rice, maize, buckwheat, beans, and vegetables (Yin et al., 2015).

Shifting cultivation is a common practice in Southeast Asian countries. In Laos, crops grown in shifting cultivation fields include rice, maize, cassava, and various other vegetables (Vongvisouk et al., 2016). In Vietnam, the main crops in shifting cultivation fields are upland rice mixed with chillies, cucumbers, and melons (Huy, 2023).

In the Democratic Republic of Congo, crops grown in shifting cultivation fields the main crop are cassava, while other crops include corn, sorghum, and upland rice. (Molinario et al., 2017). In Cameroon, shifting cultivation fields cultivate a variety of crops, including food crops such as cassava, maize, sugarcane, plantain, sweet potatoes, rice, oil palm, taro, yams, and pineapple. Additionally, cash crops such as cocoa and coffee are also grown (Pollini, 2015). In Tanzania, crops grown in shifting cultivation fields, known as 'ngoro' or 'shamba', include maize, beans, sweet potatoes, and various vegetables (Kilawe et al., 2018). The diversity of crops grown in shifting cultivation fields across different regions highlights the importance of this traditional farming system in maintaining agrobiodiversity and supporting local food security. The crop composition in these fields is influenced by local agro-ecological conditions, cultural preferences, and the nutritional needs of communities practising shifting cultivation.

The sustainability of jhum cultivation faces challenges owing to factors such as increasing population pressure, shortening of fallow periods, and soil degradation (Singh, 2024).To address these challenges, it is essential to promote sustainable land management practices, such as agroforestry, which can help maintain soil fertility, conserve biodiversity, and provide multiple benefits to local communities (Branca et al., 2013). Furthermore, the integration of traditional knowledge with modern scientific approaches can help optimise the productivity and resilience of jhum cultivation systems while preserving the cultural heritage and agro-biodiversity of the region (Parrotta et al., 2015).

5.3. Soil Quality

The soil texture in Churachandpur varies from loamy sand to sandy loam across different seasons and depths. During the pre-monsoon season, the texture was predominantly loamy sand at both depths. During the monsoon season, the texture remained loamy sand at 0-15 cm depth, but changed to sandy loam at 15-30 cm depth in some sites. In the post-monsoon season, the texture was mostly sandy loam at both the depths. The soil texture in Champhai ranges from loamy sand to sandy loam across seasons and depths. During the pre-monsoon season, the texture was mainly loamy sand at both depths. During the monsoon season, the texture was loamy sand at 0-15 cm depth and sandy loam at 15-30 cm depth. In the post-monsoon season, the texture was sandy loam at both depths at most sites. The soil texture in both regions varied from loamy sand to sandy loam, which is consistent with the findings of Mishra et al (2018ab), Ray et al. (2019), Kenye et al. (2019), and Taje et al. (2022) reported similar soil textures in the agricultural lands of northeast India. Variations in texture across seasons and depths can be attributed to factors such as parent material, weathering processes, and land management practices (Weil & Brady, 2017).

The SMC and WHC in the soils of Churachandpur and Champhai were relatively high, ranging from 15.15 ± 0.83% to 28.89 ± 0.78% for SMC and 30.28 ±

0.03% to 43.58 ± 0.17% for WHC. These values suggest that soils have good water retention properties, which can support plant growth and reduce the risk of drought stress (Osman, 2013). These findings are consistent with those reported by Singh et al. (2015) for the soils of the subtropical forest of Mizoram, where the SMC ranged from 23.66 to 28.84%. 15.67 to 20% in Manipur (Binarani & Yadava, 2010), 18.9 to 28.44 (Lodhiyal et al., 2016), 11.36 to 22.48%, (Manral et al. 2023) in Uttarakhand and 19 to 24.7% (Sunar et al., 2017), 17.4 to 23.4% (Manpoong & Tripathi, 2019), 18.5 to 30.7 (Madhurima & Mishra, 2023) under different land use system in Mizoram. Comparable results were also reported for the WHC range of 33-73.86% Deb et al. (2014) in South Sikkim, 31 to 52% (Shahi et al., 2021) in Uttarakhand, 28.70±3.35 to 49.94±5.63% (Maletha et al., 2022) in Western Himalayas, and 35.83 to 45.52% (Osman et al., 2013) in Bangladesh.

The bulk density (BD) values in the soils of Churachandpur and Champhai ranged from 0.93 ± 0.01 to 1.45 ± 0.02 g/cm^3, which is within the normal range for most soils (Chaudhari et al., 2013). These values indicate that the soil has good structure and porosity, which can facilitate root growth and water movement (Osman, 2013). The findings are consistent with those reported by Devi et al. (2017) for the soils of Senapati district, Manipur, where the BD ranged from 0.8 to 1.4 g/cm^3 across different land use systems, including jhum, forests, and plantations. Comparable results of BD 0.92 to 1.04 g/cm^3 (Mishra et al. 2019), 0.81 to 1.13 g/cm^3 (Schröder et al., 2023) were reported in Nagaland, 1.11 to 1.35 g/cm^3 (Laha et al., 2022) in Meghalaya. A study conducted in the montane forests of the Garhwal Himalaya, India, by Tiwari et al. (2023) reported that the bulk density (BD) varied significantly across different altitudes and land-use systems, with values ranging from 1 to 1.45 g/cm^3.

The pH values ranged from 5.48 ± 0.03 to 6.48 ± 0.03 in Churachandpur and 5.48 ± 0.03 to 6.42 ± 0.02 in Champhai, indicating slightly acidic to near-neutral soil conditions. Soil pH plays a crucial role in nutrient availability and plant growth, and these values are within the optimal range for most crops (Horneck et al., 2011). Similar reports of pH range were reported by Deb et al. (2014) of Sikkim, Sinha et al. (2020) from Churachandpur, Mishra et al. (2016) from tropical semievergreen forests of Nagaland, Mishra et al. (2018a) from tropical moist deciduous forests of Nagaland, Mishra et al. (2021) from land uses such as forest, jhum and fallow jhum of Nagaland, Leisangthem & Singh (2021) along riparian soil of Nagaland, Mishra & Francaviglia (2021) of different land uses such as forests, plantation, jhum and fallow hum sites from Mon and Zunheboto districts of Nagaland, Bhuvanesh et al. (2020) from Tamil Nadu, Kewlani et al. (2021) from Byans Valley, Uttarakhand, Ghosh et al. (2014) from Dehradhun, India, Lodhiyal et al. (2016) from Siwalik forest, Khumbongmayum et al. (2005) from sacred groves of Manipur.

These findings are also consistent with studies from other parts of the world, such as the Amazon rainforest in Brazil, where pH values ranged from 3.96 to 6.17 (Quesada et al., 2010), and Sichuan Province of China, where pH values ranging from 3.53 to 8.88 (Wang et al., 2023) and 4.8-6.5 from agricultural fields in China (Zhang et al. 2024). Similarly, in northeastern Victoria, Australia, Islam et al. (2006) reported soil pH ranging from 4.93-6.41, and 4.5-7.9 in acidic tropical soils (Nelson et al. 2010). Dyson et al. (202) reported pH range of 4.4-7.5 across Europe and United States of America (USA). In addition, studies on modal soil in Nigeria had a pH range of 5.3-7.3 as reported by Omofunmi & Olorunnisola (2017), Alpine soils pH ranging from 4.8-9.2 (Margesin et al., 2003), and various land uses, such as the agro-silvo-pastoral system in the Mediterranean (Seddaiu et al.,2013), Sub-Saharan Africa (Vanlauwe et al., 2015), and South America (Rozas et al., 2011) have reported pH values within the range found in this study, further supporting the findings.

The electrical conductivity (EC) values were low, ranging from 0.11 ± 0.01 to 0.26 ± 0.01 dSm^{-1} in both Churachandpur and Champhai, suggesting non-saline soil conditions. Low EC values indicate a low concentration of soluble salts, which is favourable for plant growth and development (Zörb et al., 2019). These findings were similar to those reported by Athokpam et al. (2013), Hrangbung et al. (2018), Riyabati and Sarangthem (2017), Watham et al. (2018, 2019), and Singh and Athokpam (2023) ranging from 0.070-0.517 dSm^{-1}. Behera and Shukla (2014) reported EC ranges between 0.05 and 0.09 dSm^{-1} of acidic soils of India,

These low EC values are consistent with studies from other parts of the world. For example, Corwin & Lesch (2005) reviewed the application of apparent soil electrical conductivity in precision agriculture and reported that in non-saline soils, EC values typically range from 0 to 0.2 dSm^{-1}. Jiang et al. (2007) investigated the spatial variability of soil properties in a wheat-maize cropping system in China and reported that the average soil EC ranged from 0.14 to 0.23 dSm^{-1} across different fertilizer treatments.

The soil organic carbon (SOC) content varied from 0.76 ± 0.10% to 3.53 ± 0.17% in Churachandpur and 0.76 ± 0.10% to 2.96 ± 0.08% in Champhai. These values are considered low to moderate, and a higher SOC content is generally associated with improved soil structure, water retention, and nutrient availability (Weil & Brady, 2017). Compared to other land uses, such as forests or grasslands, the SOC content in these regions may be lower because of agricultural practices and land management (Lal, 2018). These findings are consistent with previous studies conducted in various parts of India, as comparable SOC content was reported by Mishra et al. (2016, 2017, 2018b) ranging from 0.5-4.05% in Nagaland, 1.91-2.69% in Meghalaya (Bhatt & Laxminarayana, 2010) and 0.45-3.5% from soils in Churachandpur (Sinha et al. 2020). Globally, the SOC content varies widely depending on factors such as climate, vegetation, and land use. In Ethiopia, Chimdi et al. (2012) reported that SOC ranged between 2.11-4.65% under different land uses. Tellen and Yerima (2018) also recorded an SOC range between 1.83-5.79% under different land uses of Cameroon.

Avail. N ranged from 219.52 ± 18.11 to 616.75 ± 10.45 kg/ha in Churachandpur and 135.89 ± 10.45 to 616.75 ± 10.45 kg/ha in Champhai. These values indicate a wide range of nitrogen availability, with some sites having low to moderate levels and others having high levels. Nitrogen is a critical nutrient for plant growth and development, and its availability can be influenced by soil texture, organic matter content, and management practices (Robertson & Groffman, 2015). The observed range of the Avail. N is consistent with the findings of other studies in northeast India, such as Ramesh et al. (2013) from Meghalaya, Mishra et al. (2021) from Nagaland, Kumar et al. (2017) from Arunachal Pradesh, and Paul et al. (2021)from Avail. N range of 105.52 to 538.50 kg/ha from West Tripura district, Tripura, India.

Avail. P ranged from 18.10 ± 0.48 to 38.10 ± 2.86 kg/ha in both Churachandpur and Champhai. These values suggest low to moderate phosphorus availability, which may limit plant growth in some cases. Phosphorus availability is affected by soil pH, clay content, and the presence of iron and aluminium oxides (Penn & Camberato, 2019). Comparable results from the Avail. P range of 30.7-55.4 kg/ha was reported by Hota et al. (2021) in Brahmaputra Valley, Assam, 9.87-33.05 kg/ha in Garhwal, Uttarakhand (Saha et al. 2018), 14.8-47.2 kg/a in Meghalaya (Ramesh et al. 2013), 18.7-33.05 kg/ha (Ray et al. 2019), and mean value of 27.96 ±6.92 kg/ha (Mishra et al. 2021) from Nagaland.

Avail. K ranged from 144.90 ± 2.68 to 263.68 ± 1.76 kg/ha in Churachandpur and 138.28 ± 1.16 to 263.68 ± 1.76 kg/ha in Champhai, indicating moderate to high potassium availability. Potassium is essential for various plant physiological processes, and its levels are generally sufficient for most crops (Zörb et al., 2014). The observed range of the Avail. K was consistent with the findings of other studies conducted in northeast India. Mishra et al. (2016) reported Avail. K range of 150-508 kg/ha in tropical semi-evergreen forests, 156-300 kg/ha in Nagaland (Mishra et al., 2018b), 206.98-248.64 kg/ha from Wokha district of Nagaland (Ray et al. 2019), 99.42-205.88 kg/ha in Garhwal, Uttarakhand (Saha et al., 2018), 165-327 kg/ha in West Siang, Arunachal Pradesh (Kumar et al., 2017) and 153.1-380.4 kg/ha under different land uses in the Brahmaputra, Assam (Hota et al., 2022).

The Exch. Na content in the soils of Churachandpur and Champhai ranged from 1.32 ± 0.01 to 1.79 ± 0.04 cmol(p^+)/kg, which falls within the normal range for most soils. These values do not indicate any sodicity issues because the levels are well below the threshold for sodic soils (Osman, 2013). Comparable findings have been reported in other studies conducted in the northeastern region of India. For example, Mishra & Rodrigo-Comino (2021) reported that Exch. Na range of 1.5-3.5 cmol(p^+)/kg from different land uses of Nagaland. Mishra et al. (2018a) reported Exch. Na range of 0.4 to 1.34 cmol(p^+)/kg along tropical moist deciduous forests of Nagaland. Das et al. (2019) found that the Exch. Na content in different land use system of Assam, ranged from 0.03 to 0.30 cmol(p^+)/kg. In contrast, a study conducted in salt-affected soils of the Indo-Gangetic Plains of India by Mandal et al.

(2019) reported higher Exch. Na contents, ranging from 1.8 to 43.2 cmol(p^+)/kg, indicating varying degrees of sodicity in the region.

The Exch. Ca content in the soils of Churachandpur and Champhai ranged from 0.53 ± 0.13 to 1.91 ± 0.07 cmol(p^+)/kg, which is within the normal range for most soils. These values suggest that the soils have sufficient calcium levels to support plant growth and maintain the soil structure (Osman, 2013). These findings are consistent with those reported by Devi et al. (2017) for the soils of Senapati district, Manipur, where Exch. Ca content ranged from 1.2 to 4.8 cmol(p^+)/kg across different land use systems, including jhum, forests, and plantations. Similarly, a study conducted in the montane ecosystems of the Eastern Himalayas by Tashi et al. (2016) found that Exch. Ca content ranged from 0.5 to 15.0 cmol(p^+)/kg, with higher values observed in the forest soils compared to the grassland and agricultural soils. Paul et al. (2021) also reported Exch. Ca range of 0.06 to 2.68 cmol(p^+)/kg from West Tripura district, India.

The Exch. Mg content in the soils of Churachandpur and Champhai ranged from 0.95 ± 0.04 to 1.68 ± 0.03 cmol(p^+)/kg, which is within the normal range for most soils. These values indicate that the soils have adequate Mg levels to support plant growth and maintain soil fertility (Osman, 2013). Similar findings were reported by Paul et al. (2021) for the soils of West Tripura district, India, where Exch. Mg content ranged from 0.04 to 2.6 cmol(p^+)/kg. Comparable Exch. Mg range 0.21 to 1 cmol(p^+)/kg was reported by Sharma & Sarangthem (2017), 0.1 to 5.6 cmol(p^+)/kg by Hrangbung et al. (2018), .15 to 4.30 cmol(p^+)/kg by Watham et al. (2018) from Manipur, and 1.34 to 2.14 cmol(p^+)/kg by Kandali et al. (2020) from Assam, 0.4 to 1.9 cmol(p^+)/kg by Singh et al. (2013) and 0.52 to 4.36 cmol(p^+)/kg by Mishra & Francaviglia (2021) from Nagaland.

5.4. Impact of jhum cultivation on soil quality and ecosystems

Jhum cultivation, a traditional slash-and-burn farming practice, has been found to have significant adverse effects on soil quality in regions where it is widely practiced (Gogoi et al., 2020; Haokip et al. 2021). Repeated clearing and burning of vegetation lead to a substantial loss of soil organic matter and depletion of essential nutrients, such as nitrogen, phosphorus, and potassium (Kumar et al., 2023). This degradation of soil fertility can cause a decline in crop yields over successive cultivation cycles, necessitating the clearing of more land for cultivation, and exacerbating the problem of soil degradation (Gogoi et al., 2020; Haokip et al. 2021).

The loss of soil organic matter is particularly concerning, as it plays a crucial role in maintaining the soil structure, water-holding capacity, and overall soil health (Lal, 2020). The absence of organic matter can lead to increased soil erosion, reduced water infiltration, and a decline in the diversity of the soil biota, further compromising the productive capacity of the land (Lal, 2011; Koishi et al., 2020; Bashir et al., 2021).The impact of jhum cultivation on agricultural production is multifaceted, and often detrimental to long-term sustainability. Depletion of soil fertility due to the loss of organic matter and nutrients can result in lower crop yields and reduced agricultural productivity over time (Karim & Mansor, 2011; Singh, 2024).In turn, this can lead to food insecurity and economic challenges for local communities that rely on jhum farming as their primary livelihood source (Behera et al., 2015; Pandey et al., 2022a).

Furthermore, the need to clear more land for cultivation can contribute to the loss of biodiversity and ecosystem services, which can further affect agricultural productivity (Gogoi et al., 2020; Tamuli & Bora, 2022; Chaturvedi et al., 2023). The conversion of forested land to agricultural land can disrupt natural nutrient cycling processes, diminish the availability of pollinators, and reduce the provision of other ecosystem services that support sustainable food production (Gogoi et al., 2020; Lal, 2020; Tamuli & Bora, 2022).

Jhum cultivation has been closely linked to various forms of land degradation, including soil erosion, nutrient depletion, and loss of biodiversity and the clearing and burning of vegetation, coupled with the lack of long-term soil management practices, can accelerate the process of land degradation, making the land less suitable for agricultural production over time (Haokip et al, 2021; Roy et al., 2024). The loss of soil cover through the burning of vegetation can increase the susceptibility of soil to erosion by wind and water, leading to the removal of nutrient-rich topsoil (Kumar et al., 2020; Lal, 2020). This, in turn, can contribute to the depletion of soil fertility and the need for more land for cultivation, thereby perpetuating the land degradation cycle (Haokip et al, 2021; Roy et al., 2024).

Numerous studies have examined the changes in soil fertility after the implementation of jhum cultivation practices. These results consistently indicate that the fertility of the soil in areas where jhum cultivation has been practiced often declines over time (Karim & Mansor, 2011; Singh, 2024). The loss of organic matter and essential nutrients combined with the potential for soil erosion can lead to a significant reduction in the overall fertility of land (Singh, 2024). This can make it increasingly difficult to maintain high levels of agricultural productivity in these areas, as the soil may become less suitable for the cultivation of certain crops or may require the application of external inputs, such as chemical fertilisers, to sustain productivity (Karim & Mansor, 2011; Singh, 2024).

The environmental consequences of jhum cultivation, or shifting agriculture, are far-reaching and can have significant implications for ecosystem stability and the provision of vital ecosystem services (Haokip et al, 2021). The clearing and burning of vegetation can contribute to deforestation, leading to the loss of biodiversity, disruption of carbon sequestration processes, and release of greenhouse gases into the atmosphere (Chaturvedi et al., 2023). This, in turn, can exacerbate the impacts of climate change and further compromise the resilience of the affected ecosystems (Gogoi et al., 2020; Lal, 2020). Moreover, the depletion of soil fertility and the associated need for more land to be cleared can lead to the degradation of valuable ecosystems, such as forests, wetlands, and grasslands, with significant impacts on overall environmental stability and the provision of ecosystem services, such as water regulation, nutrient cycling, and the maintenance of wildlife habitats (Haokip et al., 2021; Chaturvedi et al., 2023).

The widespread practice of jhum cultivation has raised concerns regarding its potential threat to ecosystem stability in various regions (Pandey et al., 2022a; Nath et al., 2023). The clearing of land for cultivation, loss of biodiversity, and depletion of soil fertility can all contribute to the disruption of delicate ecological balances, leading to cascading effects on the overall functioning of affected ecosystems (Gogoi et al., 2020). The loss of keystone species, alteration of nutrient cycling processes, and fragmentation of habitats can threaten the stability and resilience of these ecosystems, potentially leading to further environmental degradation and loss of valuable natural resources (Lal, 2020). Addressing the sustainability of jhum cultivation practices is crucial for maintaining the overall health and stability of the affected ecosystems.

The economic implications of jhum cultivation in local communities are complex and multifaceted. While this practice can provide a means of subsistence for some communities, it also presents significant challenges. According to a study by Nath et al. (2023), the decline in soil fertility and agricultural productivity associated with jhum cultivation can lead to economic challenges, including reduced income, food insecurity, and the need for alternative livelihood strategies. Furthermore, the loss of productivity and subsequent need to clear more land for cultivation can also have indirect economic consequences. As per the findings of Dasgupta et al. (2021), these consequences include the depletion of natural resources, disruption of ecosystem services, and potential conflicts over land use. Addressing these economic implications is crucial for ensuring the long-term sustainability of agricultural practices and well-being of local communities (Lal, 2020).

Addressing the issue of land degradation associated with jhum cultivation requires a multifaceted and context-specific approach (Nath et al., 2023; Pandey et al., 2022a). Strategies may include the promotion of more sustainable farming practices such as agroforestry and the use of organic fertilisers (Rosati et al., 2020), as well as the implementation of soil and water conservation measures (Gogoi et al., 2020). The diversification of cropping patterns, the integration of livestock production (Sanderson et al., 2013), and the adoption of improved fallow management techniques (Datta et al., 2014) can also help mitigate the negative impacts of jhum cultivation on soil quality and ecosystem stability (Lal, 2020). Additionally, the provision of economic incentives (Mogaka et al., 2001), development of alternative livelihood options (Basu, 2021), and involvement of local communities in the decision-making process (Mogaka et al., 2001) can all contribute to the successful implementation of these strategies (Pandey et al., 2022a).

As the detrimental impacts of jhum cultivation on soil degradation become more widely recognised, the future of agriculture in regions where this practice has prevailed may shift towards more sustainable approaches. This shift could involve the adoption of alternative farming methods, implementation of soil conservation strategies, and diversification of livelihoods, all of which could contribute to a more resilient and environmentally friendly agricultural landscape (Ayyam et al., 2019; Dasgupta et al., 2021). However, this transition will require collaborative efforts of policymakers, researchers, and local communities to ensure the long-term sustainability of agricultural practices (Gogoi et al., 2020; Singh, 2024). The integration of traditional ecological knowledge with modern scientific understanding, the provision of technical and financial support, and the empowerment of local communities can all play a crucial role in shaping the future of agriculture in regions where jhum cultivation has been a dominant practice (Whyte, 2013; Nugroho et al., 2023; Rasmussen, 2023).

In response to the negative impacts of jhum cultivation on soil degradation, several sustainable alternatives have been proposed and implemented in various regions (Singh, 2019; Haokip et al., 2021). These alternatives include the adoption of agroforestry systems (Pandey et al., 2022ab), use of organic fertilisers (Grogan et al., 2012; Baishya et al., 2022), implementation of soil and water conservation measures89, and integration of more diverse cropping patterns (Giri et al., 2020; Payum et al., 2021; Pandey et al., 2022a; Lal, 2020). Agroforestry systems, for example, can help maintain soil fertility by incorporating trees and shrubs into the farming system, which can contribute to the replenishment of organic matter and the cycling of nutrients (Pandey et al., 2022ab).Similarly, the use of organic fertilisers, such as compost or green manure, can help restore soil fertility, improve soil structure, reduce reliance on external inputs, and promote more sustainable agricultural practices (Grogan et al., 2012; Baishya et al., 2022).

5.5. Impact of altitude on soil quality

The effect of altitude on soil properties has been a topic of interest in various ecosystems worldwide, including jhum cultivation systems. This study investigated the influence of altitude on soil properties in the jhum cultivation systems of Churachandpur and Champhai, and found that altitude plays a significant role in shaping soil characteristics, as it influences factors such as climate, vegetation, and weathering processes (Charan et al., 2013). In Churachandpur, the analysis revealed significant differences in the soil properties across different altitudinal gradients.

The sand content was higher at higher altitudes than at lower altitudes, which can be attributed to differences in parent material, weathering processes, and erosion rates (Yang et al., 2008; Charan et al., 2013). This pattern is consistent with findings from other tropical regions, such as the Western Ghats of India, where higher altitudes are associated with coarser soil textures (Putty et al., 2021). Similarly, studies in the Ethiopian highlands (Lemenih & Itanna, 2004) and the Andes of South America (Muñoz et al., 2015) have reported higher sand content at higher elevations.

The soil texture in the altitudinal gradient of <500 m (KG and KK) varied from loamy sand to sandy loam across seasons and depths. Similar texture ranges were observed at the 500-1000 m (EP and NE) and <1000 m (HK and KB) gradients, with a higher proportion of sandy loam in the post-monsoon season. These findings are consistent with the observations made by Luo et al. (2023) in the Fanjing Mountains of Southwest China, where the soil texture became coarser at higher altitudes owing to the influence of parent material and weathering processes. The soil texture in the jhum cultivation sites of Churachandpur and Champhai varied across different altitudinal gradients. At altitudes below 500 m (sites KG and KK), soil texture ranged from loamy sand to sandy loam across seasons and depths. During the pre-monsoon season, the texture was predominantly loamy sand at both 0-15 cm and 15-30 cm depths. In the monsoon season, the texture remained loamy sand at 0-15 cm depth, but changed to sandy loam at 15-30 cm depth in some cases. Post-monsoon, the texture was mostly sandy loam at both the depths. At altitudes of 500-1000 m (sites EP and NE), the soil texture varied from loamy sand to sandy loam across seasons and depths. During the pre-monsoon season, the texture was loamy sand to sandy loam at 0-15 cm depth and loamy sand at 15-30 cm depth. During the monsoon season, the texture was loamy sand at both depths. After the monsoon season, the texture was sandy loam at 0-15 cm depth and loamy sand at 15-30 cm depth. At altitudes above 1000 m (sites HK and KB), soil texture ranged from loamy sand to sandy loam across seasons and depths. In the pre-monsoon season, the texture was loamy sand at both the depths. During the monsoon season, the texture remained loamy sand at both 0-15 cm and 15-30 cm depths. After the monsoon season, the texture was sandy loam at 0-15 cm depth and loamy sand at 15-30 cm depth.

Variations in soil texture across altitudinal gradients can be attributed to factors such as parent material, climate, and topography (Weil & Brady, 2017). In a study conducted in the hilly mountainous regions of Khyber Pakhtunkhwa Pakistan, Kamal et al. (2023) found that soil texture varied significantly across different altitudinal gradients and that sand and clay content increased with increasing altitude.

A study conducted in two districts of Nagaland, Northeast India, found that soil properties, including texture, varied significantly with land-use and altitudinal gradients. The study observed that soil organic carbon stocks and available potassium were significantly influenced by land use, and soil texture significantly affected these properties (Mishra & Francaviglia 2021). Another study conducted in the Ecuadorian Amazon region found significant variations in soil properties, including bulk density, saturated hydraulic conductivity, total porosity, soil organic matter, total nitrogen, available phosphorus, potassium, and exchangeable calcium along an altitudinal gradient (Bravo et al. 2023).

In the context of jhum cultivation, the predominance of loamy sand and sandy loam textures across altitudinal gradients suggests that these soils have a higher proportion of sand particles, which can influence soil properties, such as water retention and nutrient holding capacity (Osman, 2013). The higher sand content at the upper elevations may be due to the increased weathering and erosion processes associated with steep slopes and high rainfall. This is particularly evident in areas with fragile geological structures, such as the Loess Plateau, where the rainfall-induced erosion of high and steep slopes has been extensively studied (Li et al. 2020). Research on the induced pattern of landslides under rainfall conditions on high and steep slopes further supports this observation (Jin et al. 2023).

Variations in the soil texture across altitudinal gradients have important implications for land management and crop productivity in jhum cultivation systems. Sandy soils are generally less fertile and have a lower water holding capacity than clayey soils (Osman, 2013). Therefore, the predominance of sandy textures in upper elevations may require specific management practices, such as the use of organic amendments and soil conservation measures, to improve soil fertility and productivity. This is particularly evident in areas with sandy soils, where the application of organic amendments has been shown to significantly affect soil properties (Degala et al. 2018).

SMC and WHC were lower at higher altitudes in Churachandpur and Champhai, which could be due to coarser soil texture and lower precipitation (Dong & Ochsner, 2018). This trend is similar to that observed in the subtropical region of China, where SMC and WHC decrease with increasing altitude (Du et al., 2021; Nie et al., 2023).

The bulk density (BD) also remained within a comparable range across the gradients. These results are in line with the findings of Tellen and Yerima (2018), who studied the effects of land-use change and altitude on soil properties in the Bamenda Highlands of Cameroon. Soil pH and electrical conductivity (EC) exhibited similar ranges across all altitudinal gradients, indicating slightly acidic to near-neutral soil conditions and low salinity. Kamal et al. (2023) found that soil pH decreased with increasing altitude in different land use systems. This decrease in soil pH has been attributed to factors such as lower temperature, higher precipitation, and leaching at higher altitudes (Kumar et al., 2024).

Altitude also influences soil chemical properties, such as pH, organic carbon, and nutrient availability. In the jhum cultivation systems of Champhai, variations in soil pH and organic carbon content were observed along the altitudinal gradient.

These findings are in line with studies conducted in other montane regions, such as the Himalayan mountains (Manhas et al., 2006), Siang River basin in Arunachal Pradesh (Tasung & Ahmed, 2017), temperate forests of Kashmir (Dar & Sundarapandian, 2015), sub-tropical Himalayan forests (Kumar et al., 2024) low-latitude plateau of Yunnan Province, southwest China (Zhou et al., 2023) and jhum fields in Arunachal Pradesh (Kumar et al., 2023), where higher altitudes were associated with lower soil pH and higher organic carbon content.

Nutrient availability is another crucial aspect of soil quality that is affected by altitude. In both Churachandpur and Champhai, the available nitrogen, phosphorus, and potassium varied across different altitudinal ranges. These observations are consistent with studies from the Tibetan Plateau (Luo et al., 2020) and the montane forests of Malaysia (Kitayama & Aiba, 2002), which have reported variations in nutrient availability along altitudinal gradients. Comparing the results from jhum cultivation systems with those of other land uses and regions provides valuable insights into the effect of altitude on soil properties. Studies conducted in the Indian Himalayan region (Tashi et al., 2016) and alpine regions of Tibet (Wang et al., 2023), subtropical Himalayan forests (Kumar et al., 2024), and south-central Ethiopia (Kebebew et al., 2022) have demonstrated the influence of altitude on soil properties across different land-use types, including forests, grasslands, and agricultural systems.

In both Champhai and Churachandpur, the soil organic carbon (SOC) and available nutrient contents decreased with increasing altitude. This trend, which is consistent with the findings of Shedayi et al. (2016) and Tong et al. (2024), can be attributed to factors such as lower temperatures, higher precipitation, and leaching at higher altitudes. These factors influence the accumulation and decomposition of organic matter, leading to a lower SOC content at higher altitudes. This pattern has also been observed in other tropical and subtropical regions (Du et al., 2021; Chương et al., 2022; Nie et al., 2023). The lower SOC content at higher altitudes in these regions could be due to lower biomass production and litter accumulation (Bhardwaj et al., 2023), a pattern that is consistent with findings from other tropical regions such as the Western Ghats of India (Joseph et al., 2020).

The Avail. N content in the soils of Champhai and Churachandpur showed a decreasing trend with increasing altitude, which is in line with the observations of soil organic carbon content. This pattern can be attributed to the influence of factors, such as lower temperature, higher precipitation, and leaching at higher altitudes, which affect the mineralisation and availability of nitrogen in the soil (Woo et al., 2022; Hou et al., 2023). Additionally, the lower OC content at higher altitudes may contribute to the reduced availability of nitrogen, as organic matter is a major source of nitrogen in the soil (Du et al., 2021; Nie et al., 2023). Similar trends were observed for the Avail. N content along altitudinal gradients has been reported in other mountainous regions, such as the Himalayas (Tashi et al., 2016) and the Andes (Segnini et al., 2010), where lower temperatures and higher precipitation at higher altitudes influence nitrogen mineralisation and availability.

The Avail. P contents in the soils of Champhai and Churachandpur also decreased with increasing altitude. This pattern can be attributed to the influence of factors such as lower temperature, higher precipitation, and leaching at higher altitudes, which affect the solubility and availability of phosphorus in the soil (Xu et al., 2013; Attar et al., 2022; Zhu et al., 2022; Anjum et al., 2024). Additionally, the lower OC content at higher altitudes may contribute to the reduced availability of phosphorus, as organic matter plays a role in the retention and release of phosphorus in the soil (Tellen & Yerima, 2018). Similar trends were observed for the Avail. P content along altitudinal gradients has been reported in other mountainous regions, such as the Evergreen Andean-Amazonian Forest, Ecuador (Bravo et al., 2023), Mt. Gongga, southwest China (Zhou et al., 2016), subtropical karst mountains of China (Nie et al., 2023), and the Western Ghats of India (Verma et al., 2019), where soil pH and organic matter content influence phosphorus availability.

The Avail. The K content in the soils of Champhai and Churachandpur decreased with increasing altitude, similar to the patterns observed in Avail. N and Avail. P. This trend can be attributed to the influence of factors such as lower temperature, higher precipitation, and leaching at higher altitudes, which affect the solubility and availability of potassium in the soil (Kaur, 2019; Attar et al., 2022). Additionally, the lower OC content at higher altitudes may contribute to the reduced availability of potassium, as organic matter plays a role in the retention and release of potassium in the soil (Tellen & Yerima, 2018). Similar trends were observed for the Avail. K content along altitudinal gradients has been reported in other mountainous regions, such as the Peruvian Andes (Segnini et al., 2010) and Himalayas (Tashi et al., 2016), where soil weathering and leaching processes influence potassium availability.

The Exch. Na content in the soils of Champhai and Churachandpur did not show a clear trend with increasing altitude, suggesting that other factors such as parent material, weathering processes, and land use practices may have a stronger influence on sodium availability in these regions (Tellen & Yerima, 2018). However, in some studies, Exch. Na content has been found to increase with altitude because of the accumulation of sodium ions in the soil as a result of reduced leaching and weathering processes at higher altitudes (Negasa, 2020; Segnini et al., 2010). The lack of a clear trend in Exch. Na content in Champhai and Churachandpur highlights the need for further investigation into the specific factors influencing sodium dynamics in these regions.

The Exch. Ca content in the soils of Champhai and Churachandpur did not exhibit a clear trend with increasing altitude, suggesting that other factors such as parent material, weathering processes, and land use practices may have a stronger influence on calcium availability in these regions (Tellen & Yerima, 2018). However, in some studies, Exch. Ca content has been found to decrease with altitude due to the influence of leaching and weathering processes at higher altitudes (Negasa, 2020; Segnini et al., 2010).

The Exch. Mg content in the soils of Champhai and Churachandpur did not show a clear trend with increasing altitude, suggesting that other factors, such as parent material, weathering processes, and land-use practices, may have a stronger influence on magnesium availability in these regions (Tellen & Yerima, 2018). However, in some studies, Exch. Mg content has been found to decrease with altitude because of the influence of leaching and weathering processes at higher altitudes (Negasa, 2020; Segnini et al., 2010).

In a study conducted in the Western Ghats of India, Sonaimuthu et al. (2018) and Jagadesh et al. (2023) found that soil properties such as pH, OC, and available nutrients were significantly influenced by land use and altitude. They observed that forest soils had higher OC and nutrient contents than agricultural and plantation soils, and that these properties decreased with increasing altitude.

Similarly, Negasa (2020) investigated the effects of altitude and land use on soil properties in the central highlands of Ethiopia and found that soil pH, OC, and available nutrients were higher in forest soils than in agricultural and grazing lands. They also observed that these properties decreased with increasing altitude, which they attributed to the differences in climate, vegetation, and management practices.

In a study conducted in the Ecuadorian Amazon region, Bravo et al. (2023) found that soil properties, such as pH, OC, and available nutrients, varied significantly across different altitudinal gradients and land use types. They observed that high-altitude grasslands had lower pH and nutrient content than low-altitude agricultural lands, which they attributed to differences in the climate, vegetation, and soil development processes. Available nutrients such as nitrogen (N), phosphorus (P), and potassium (K) also decreased with increasing altitude, which could be due to the lower organic matter content and nutrient retention in soils at higher altitudes (Rao et al., 2015).This trend is similar to that observed in the subtropical region of China, where the available nutrient content decreases with increasing altitude (Du et al., 2021; Nie et al., 2023).

These studies highlight the complex interplay of factors such as altitude, land use, climate, and vegetation in shaping the soil properties across different regions. The findings from Churachandpur and Champhai are consistent with the general trends observed in other mountainous regions, where soil quality tends to be influenced by altitudinal gradients and land-use practices. However, the specific trends and magnitudes of variation may differ depending on local environmental conditions and management practices.

5.6. Effect of Seasons on soil quality

The impact of season on soil physical and chemical properties was investigated in the jhum cultivation systems of Churachandpur and Champhai, and the results revealed distinct patterns across different seasons. In both regions, the soil moisture content (SMC) and water holding capacity (WHC) exhibited significant seasonal variations, with higher values during the monsoon season than in the pre- and post-monsoon seasons at both 0-15 cm (topsoil) and 15-30 cm (subsoil) depths. For example, in Churachandpur, the SMC in the topsoil was 23.01 ± 0.25% during the monsoon season, compared to 19.17 ± 1.18% and 17.8 ± 0.23% during the pre-monsoon and post-monsoon seasons, respectively. Similarly, in Champhai, the SMC at the same depth was 28.89 ± 0.78% during the monsoon season, compared to 24.51 ± 0.91% and 20.23 ± 0.73% during the pre-monsoon and post-monsoon seasons, respectively. Increased precipitation during the monsoon season replenishes soil moisture, which can promote nutrient availability and support crop growth (Venkatraman, 2014).This pattern of higher SMC and WHC during the monsoon season has also been observed in other regions such as the Chittagong Hill Tracts of Bangladesh (Hassan et al., 2017), where jhum cultivation is practiced.

Soil chemical properties also showed significant seasonal variation in both Churachandpur and Champhai. The soil pH was lower during the monsoon season than during the pre- and post-monsoon seasons in the topsoil in both regions, which could be due to the leaching of basic cations during the rainy season (Kumar & Mohanta, 2009; Rengel, 2011).This trend of lower soil pH during the monsoon season has also been reported in other jhum cultivation areas, such as Nagaland (Semy et al., 2022) and the tropical dry deciduous forests of Madhya Pradesh (Solanki et al. 2024). However, in some cases, the soil pH has been found to increase during the monsoon season because of the deposition of base-rich sediments (Yadav et al. 2019; Lepcha & Devi, 2020; Solanki et al. 2024).

The soil organic carbon (SOC) content in both Churachandpur and Champhai was higher in the topsoil during the pre-monsoon season than during the monsoon and post monsoon seasons. This could be attributed to the accumulation of litter and biomass during the dry season, a pattern observed in the jhum practices of northeastern states of India (Gogoi et al., 2020; Nath et al., 2023). In certain instances, such as in the eastern Himalayas of Nepal, Bhutan, and parts of northeast India, the SOC content has been observed to rise during the monsoon period due to the integration of new organic matter from the local flora (He et al., 2021).Similar trends have been reported in other monsoon-affected areas, such as the Western Ghats in India (Babu et al., 2023) and the Chittagong Hill Tracts in Bangladesh (Biswas et al., 2011).

Available nutrients, such as nitrogen (N), phosphorus (P), and potassium (K), showed significant seasonal variations in both Churachandpur and Champhai, with higher values during the monsoon season than in the pre-monsoon and post-monsoon seasons at both depths. This trend can be attributed to the increased mineralisation of organic matter and the release of nutrients from soil minerals during the rainy season (Yadav et al., 2019).Similar patterns of higher nutrient availability during the monsoon season have been reported in other jhum cultivation areas in northeastern India (Gogoi, 2020; Dasgupta et al., 2021).

Seasonal variations in soil properties have important implications on crop growth and productivity in jhum cultivation systems. A higher soil moisture content and nutrient availability during the monsoon season can support crop growth and yield (Grogan et al., 2012). However, intense rainfall during the monsoon season can also lead to soil erosion and nutrient leaching, which can negatively affect soil fertility and crop productivity (Gogoi, 2020; Dasgupta et al., 2021). This dual effect of the monsoon season on soil properties and crop productivity has been observed in various jhum cultivation regions such as the uplands of Vietnam (Do et al., 2019).

To mitigate the negative effects of seasonal variations on soil properties and crop productivity, sustainable management practices can be adopted in commercial cultivation systems. These practices include the use of soil conservation measures such as contour farming, mulching, and cover cropping, which can reduce soil erosion and improve soil moisture retention (Pandey et al., 2022b; Dasgupta et al., 2023).Additionally, the incorporation of leguminous crops into the cropping cycle can help improve soil fertility through biological nitrogen fixation (Kebede, 2021). Similar sustainable management practices have been recommended for jhum cultivation systems in other regions, such as the Chittagong Hill Tracts of Bangladesh (Hossain et al., 2015) and northeastern states of India (Gogoi, 2020; Dasgupta et al., 2021; Singh, 2024).

Seasonal variations have a significant impact on soil physical and chemical properties in the jhum cultivation systems of Churachandpur and Champhai. The monsoon season is characterised by higher soil moisture content and nutrient availability, which can support crop growth and productivity. However, intense rainfall during the monsoon season can lead to soil erosion and nutrient leaching. These patterns are consistent with findings from other jhum cultivation regions worldwide, although some variations exist because of local environmental conditions. Sustainable management practices, such as soil conservation measures and the incorporation of leguminous crops, can help mitigate the negative effects of seasonal variations on soil properties and crop productivity in jhum cultivation systems. Such practices have been recommended for jhum cultivation systems in various regions, highlighting the need for a context-specific approach for sustainable land management in these agroecosystems.

5.7. Maize Growth and Yield

Maize growth and yield performance varied across the study sites in Churachandpur and Champhai, with plant height, leaf number, and LAI showing differences among the sites, particularly during the early growth stages. However, these differences did not significantly affect the final maize yield, which ranged between 816.96 ± 17.10 to 894.72 ± 41.48 kg/ha. Sati (2020) had reported the yield range of maize in Mizoram however, these yield levels are considerably lower compared to the average maize yield in India, which was reported to be 3,023 kg/ha in 2018-19 (Directorate of Economics and Statistics, 2020). The lower yields in the current study could be attributed to the use of traditional jhum cultivation practices, which involve minimal inputs and rely on natural soil fertility (Thong et al., 2018). Jhum cultivation, a common practice in the northeastern region of India, involves farmers cultivating crops on slopes after clearing the forest vegetation (Pasha et al., 2020; Wapongnungsang et al., 2021) often leading to soil erosion, nutrient depletion, and low crop productivity (Baptista et al., 2015; Bashagaluke et al., 2018; Musa et al., 2024).

Biomass accumulation and harvest index (HI) also varied among the sites. In Churachandpur, KG had a higher biomass (409.35 ± 25.35 g) compared to KK (429.27 ± 13.85 g), while in Champhai, KB had a higher biomass (468.13 ± 10.38 g) compared to HK (368.578 ± 18.26 g). The Harvest Index (HI), a key indicator of the efficiency of assimilate partitioning towards economic yield, has been extensively studied in recent years (Meng et al., 2024) and was similar across the sites, ranging from 0.32 ± 0.01 to 38.15 ± 0.93%. These HI values are within the range reported for maize in other studies. For instance, Hai et al. (2023) reported HI values ranging from 0.37 to 0.48 for maize grown under different county in China from 2001-2019.

Similar maize yields were reported by Sati (2020) in Mizoram; however, compared to other maize-growing regions in India, the yields obtained in the current study were much lower. Field experiment conducted by Ramkrushna et al., (2022) reported that the yield of maize decline considerably to 1.91 t/ha in second year and 2.13 t./ha in first year under farmers practice (jhum) in Meghalaya. A study conducted in Umniam, Meghalaya by Layek et al. (2016) of different maize cultivars have yield of 2.62 to 3.39 tons per hectare (t/ha) under organic production system. A study by Manjunatha et al. (2018) in Karnataka, South India reported maize yields ranging from 6,060 to 11,110 kg/ha under different nutrient management practices. The higher yields in these studies could be attributed to the adoption of improved management practices, such as optimum nutrient application, irrigation, and use of high-yielding varieties.

Globally, the maize yields in the current study were lower than those reported in some major maize-producing countries. For example, in a study conducted at Dera Ismail Khan, Pakistan, Abuzar et al., (2011) reported that the yield of maize differs significantly depending on the densities from 746.3 to 2604 kg/ha after application of various fertilisers. A study in Nepal by Adhikari et al. (2023), reported that the yield of maize differs from 7.63 to 8.46 t/ha under different nitrogen level treatment. In China, the average maize yield was 6,110 kg/ha in 2018 (FAO, 2020). In a field experiment conducted in Bangladesh by Tajul et al. (2013), under different levels of nitrogen fertiliser treatments, plant densities, and spacing, the maize yield varied from 2.52 to 5.03 t/ha higher yields in these countries can be attributed to the use of advanced technologies such as precision farming, improved varieties, and optimised input management (Chen et al., 2011; Li et al., 2020).

Various factors have a substantial impact on the production of maize in jhum fields in Northeast India. Low yields have been attributed to the use of indigenous cultivars, inadequate management techniques, and inadequate supply of essential nutrients, such as phosphorus, and the presence of harmful substances, such as iron and aluminium, which are commonly associated with soil acidity, also impede production (Layek et al., 2015; Ramkrushna et al., 2023). The jhum cycle, which has been significantly reduced to 5 to 6 years as a result of escalating population pressure, is inadequate for land rejuvenation, resulting in ecological imbalances, decreased yields, and food insecurity (Haokip et al., 2021). The conversion of natural vegetation to shifting agriculture leads to soil erosion and degradation of fertility (Sati, 2020; Kumar, 2023) which significantly decreases maize yields.

5.8. Cucumber Growth and Yield

Cucumber growth parameters, such as vine length, leaf number, and LAI, varied among the study sites. At 30 DAS, NE had a higher vine length than EP in Churachandpur, while KB had a higher vine length than HK in Champhai. However, these differences did not consistently persist throughout the growth stages. The fruit yield was significantly higher in KG (1380 ± 96.95 kg/ha) and NE (1520 ± 48.99 kg/ha) compared to their counterparts in Churachandpur and Champhai, respectively. Biomass and HI were similar across the sites, suggesting that the differences in vegetative growth did not translate into significant differences in fruit yield or biomass allocation.

The cucumber yields obtained in this study were much lower than those reported in other regions of India and outside India. In a study conducted in the Meghalaya, Verma et al. (2022) reported cucumber yields ranging from 13.9 to 31.8 tons per hectare (t/ha) under different lime and mulching treatments. Shaju et al. (2020) reported yields ranging from 22.3 to 59.7 t/ha of different cucumber hybrids in Uttar Pradesh, India. Similarly, Longjam & Devi (2017) reported yield of 17.40 to 47.31 t/ha under different treatments and planting time under polyhouse conditions in Manipur. In Nigeria, Eifediyi & Remison (2009), reported yield of 20906.85 to 41098.03 kg/ha of five different varieties of cucumber and at different planting time. Wahocho et al. (2016) reported cucumber yields of 5.34 to 18.81 t/ha under different nitrogen levels treatment Pakistan. The higher yields in these studies could be attributed to the use of improved varieties, optimised irrigation, and fertiliser management practices (Mohammadi & Omid, 2010; Liang et al., 2016). These studies highlight the importance of appropriate management practices, such as mulching and nutrient management, for improving cucumber yield. The low yields of cucumber in jhum fields in Churachandpur and Champhai are mostly caused by soil erosion, which results in changes in the physical and chemical qualities of the soil (Nath et al. 2016), together with the shortening of jhum cycles, prevents the regeneration of nutrients, leading to a fall in yield and output (Tamuli & Bora, 2021; Haokip, 2021).

Several factors can influence cucumber growth and yield, including soil fertility, irrigation, pest and disease management, and the use of improved varieties (Eifediyi & Remison, 2010; Zhang et al., 2017). In the context of jhum cultivation, the low yields observed in the current study could be due to the limited use of inputs and reliance on natural soil fertility (Thong et al., 2018, 2019a). Improving soil fertility through the use of organic amendments such as compost and green manure could potentially enhance cucumber yields in these systems (Alam et al., 2014; Moyin-Jesu, 2015).Moreover, the adoption of integrated pest and disease management strategies, such as the use of resistant varieties, crop rotation, and biological control agents, could help minimise yield losses due to biotic stress (Bhat et al., 2013).The use of protected cultivation techniques, such as low tunnels and net houses, could also help extend the growing season and improve the yield and quality of cucumber (Reddy, 2016; Rajiv & Kumari, 2023; Kumar et al., 2024).

In conclusion, the maize and cucumber growth and yield performance in the jhum fields of Churachandpur and Champhai were influenced by site-specific factors. Maize yields were lower than the national average and other maize-growing regions in India and abroad, while cucumber yields were also lower than those reported in other parts of the country. The lower yields could be attributed to traditional jhum cultivation practices, which involve minimal input and rely on natural soil fertility. Improving soil fertility, adopting integrated pest and disease management strategies, and using protected cultivation techniques could potentially enhance maize and cucumber productivity in these regions. Future research should focus on identifying and addressing site-specific constraints, and developing sustainable management practices to improve the livelihoods of farmers engaged in jhum cultivation.

CHAPTER 6

SUMMARY AND CONCLUSION

This comprehensive study has provided valuable insights into the comparative analysis of jhum cultivation practices and their effects on crop composition, soil characteristics, crop production, and economic viability in Manipur and Mizoram, India. The present research selected Churachandpur and Champhai districts as the primary loci of investigation due to the prevalence of jhum cultivation practices among the local populace within these regions. From the designated study sites, three distinct sampling locations were identified based on their altitudinal gradients, encompassing elevations below 500 meters above mean sea level (AMSL), between 500-1000 AMSL, and exceeding 1000 AMSL. The specific sampling sites chosen from Churachandpur district include Khuanggin, Enpum, and D. Hengkot, while the selected sites from Champhai district are Khawkawn, NE Khawdungsei, and Kawlbem.

Soil samples were collected in replicates from each of the designated sampling sites during the pre-monsoon (March – June), monsoon (July – October), and post-monsoon (November – February) seasons, and the physical and chemical properties of the collected soil samples were analysed at the ICAR-RC facility located in Lamphelpat, Imphal, following well-established laboratory procedures outlined in Anderson & Ingram (1993), Bernard (1963), Walkley & Black (1934), Subbiah & Asija (1956), Bray & Kurtz (1954), and Hanway & Heidal (1952).

Crop growth and yield were also analysed from each sampling site, with maize and cucumber selected as the focus crops for this analysis as they were present in all the sampling sites; for the maize plants, the number of leaves, Leaf Area Index (LAI), number of cobs per plant, weight of the corn biomass, and harvest index, were recorded and analysed, while for the cucumber plants, the vine length, LAI, number of leaves per plant, number of fruits per plant, weight of the fruits, yield per hectare, total biomass, and harvest index were recorded and analysed. Thus, providing a comprehensive assessment of the agricultural productivity across the sampling sites and seasons.

The jhum fields were also evaluated for their economic viability using Cost-Benefit Analysis. The costs associated with jhum cultivation, including land preparation, crop establishment, maintenance, and harvesting, were carefully documented and analysed. Similarly, the benefits derived from the jhum systems, such as the monetary value of the harvested crops, were quantified. By comparing the total costs and benefits, the economic efficiency and profitability of the jhum farming practices were assessed. This cost-benefit analysis provided crucial insights into the economic sustainability of the traditional jhum cultivation systems practiced within the study region.

The following results were obtained from the in-depth analysis:

1. The mode of operation in the jhum fields was found to be remarkably consistent across the study sites in both districts. The cultivation process followed a similar pattern, with minor variations in field size (ranging from 1 to 1.4 ha), seed sowing schedules (mostly in March), and labour requirements (two to three people per field). This highlights the shared cultural and ecological context of the region and the common challenges faced by jhum cultivators, such as soil erosion, declining soil fertility, and the need for sustainable land management practices.
2. Crop composition analysis revealed similarities and variations across the study sites. Cucurbitaceae and Poaceae were the most common families, with cucumber and maize consistently growing at all sites. Other common crops include beans, pumpkins, and taros. The diversity of crops grown in the jhum fields, with an average of 8 to 13 different crops per site, highlights the importance of the jhum system in maintaining agro-biodiversity and supporting local food security.
3. The sand content in Churachandpur ranges from 63.17 ± 0.03% to 85.71 ± 0.01%. It was highest at site HK (85.71 ± 0.01%) during the monsoon season in the surface (0-15 cm) layer, whereas the lowest was observed at site EP (63.17 ± 0.03%) during the post-monsoon season in the surface layer. In Champhai, the sand content ranges from 63.56 ± 0.04% to 90.86 ± 0.14%. It was highest at site KB (90.86 ± 0.14%) during the monsoon season in the subsurface (15-30 cm) layer, while the lowest was observed at site KK (63.56 ± 0.04%) during the post-monsoon season in the surface layer.

4. In Churachandpur, silt content showed considerable variation, ranging from 4.8 ± 0.05% to 31.32 ± 0.29%. The highest silt content was observed at site EP, measuring 31.32 ± 0.29% in the surface layer (0-15 cm) during the post-monsoon season. Conversely, the lowest silt content was found at site KG, with a value of 4.8 ± 0.05% in the surface layer during the post-monsoon season. The silt content in Champhai exhibited a wide range, varying from 2.10 ± 0.07% to 28.4 ± 0.17%. The maximum silt content was recorded at site KK, reaching 28.4 ± 0.17% in the subsurface layer (15-30 cm) during the pre-monsoon season. In contrast, the minimum silt content was observed at site KB, measuring 2.10 ± 0.07% in the subsurface layer during the monsoon season.
5. In Churachandpur, the clay content exhibits a considerable range, varying from 2.28 ± 0.08% to 19.82 ± 0.06%. The highest clay content was observed at site KG, measuring 19.82 ± 0.06% in the surface layer (0-15 cm) during the post-monsoon season. In contrast, the lowest clay content was recorded at site EP, with a value of 2.28 ± 0.08% in the surface layer during the pre-monsoon season. The clay content in Champhai varied significantly, ranging from 1.73 ± 0.03% to 14.5 ± 0.06%. The maximum clay content was found at site KK, reaching 14.5 ± 0.06% in the subsurface layer (15-30 cm) during the monsoon season. Conversely, the minimum clay content was observed at site KB, measuring 1.73 ± 0.03% in the subsurface layer during the pre-monsoon season.
6. The soil texture in Churachandpur was predominantly loamy sand to sandy loam, whereas the soil texture in Champhai was predominantly loamy sand to sandy loam, similar to that in Churachandpur, indicating comparable water retention and drainage characteristics across both districts.
7. In Churachandpur, the soil moisture content (SMC) demonstrated significant variation, ranging from 15.15 ± 0.83% to 28.89 ± 0.78%. The highest SMC was recorded at site EP, measuring 28.89 ± 0.78% in the surface layer during the monsoon season. Conversely, the lowest SMC was observed at site EP, with a value of 15.15 ± 0.83% in the subsurface layer (15-30 cm) during the pre-monsoon season. The soil moisture content (SMC) in Champhai exhibited a similar range to that of Churachandpur, varying from 15.15 ± 0.15% to 28.89 ± 0.78%. The maximum SMC

was found at site NE, reaching 28.89 ± 0.78% in the surface layer (0-15 cm) during the monsoon season. In contrast, the minimum SMC was recorded at site KK, measuring 15.15 ± 0.15% in the subsurface layer (15-30 cm) during the pre-monsoon season.

8. In Churachandpur, WHC ranged from 30.28 ± 0.03% to 43.18 ± 0.12%, with the maximum observed at site KG (43.18 ± 0.12%) during the monsoon season in the surface layer (0-15 cm) and the minimum at site EP (30.28 ± 0.03%) in the pre-monsoon subsurface layer (15-30 cm). In Champhai, WHC ranged from 31.91% to 44.71 ± 0.75%, with the maximum recorded at site KB (44.71 ± 0.75%) during the monsoon season in the surface layer and the minimum at site KK (31.91%) in the pre-monsoon surface layer.
9. In Churachandpur, BD ranged from 0.89 ± 0.01 g/cm³ to 1.45 ± 0.02 g/cm³, with the highest value at site EP (1.45 ± 0.02 g/cm³) during the monsoon season in the subsurface layer and the lowest at site KG (0.89 ± 0.01 g/cm³) in the pre-monsoon surface layer. In Champhai, BD ranged from 0.89 ± 0.01 g/cm³ to 1.45 ± 0.02 g/cm³, with the highest value at site KK (1.45 ± 0.02 g/cm³) during the monsoon season in the subsurface layer and the lowest at site KB (0.89 ± 0.01 g/cm³) in the pre-monsoon surface layer.
10. In Churachandpur, pH ranged from 5.48 ± 0.03 to 6.48 ± 0.03, with the highest pH observed at site KG (6.48 ± 0.03) during the pre-monsoon season in the surface layer, and the lowest at site EP (5.48 ± 0.03) during the monsoon season in the subsurface layer. In Champhai, pH ranged from 5.48 ± 0.03 to 6.26 ± 0.18, with the highest pH observed at site KB (6.26 ± 0.18) during the pre-monsoon season in the subsurface layer, and the lowest at site NE (5.48 ± 0.03) during the monsoon season in the subsurface layer.
11. In Churachandpur, EC ranged from 0.11 ± 0.02 dSm^{-1} to 0.26 ± 0.01 dSm^{-1}, peaking at site KG (0.26 ± 0.01 dSm^{-1}) during the post-monsoon season in the surface layer and reaching its minimum at sites EP and HK (0.11 ± 0.02 dSm^{-1}) during the monsoon season in the subsurface layer. In Champhai, EC ranged from 0.11 ± 0.02 dSm^{-1} to 0.24 ± 0.02 dSm^{-1}, peaking at sites KK and KB (0.24 ± 0.02 dSm^{-1}) during

the post-monsoon season in the surface layer and reaching its minimum at site KK (0.11 ± 0.02 dSm^{-1}) during the monsoon season in the subsurface layer.

12. In Churachandpur, SOC ranged from 1.25 ± 0.03% to 3.53 ± 0.17%.The highest SOC in the subsurface layer was recorded at site HK (3.53 ± 0.17 %) during the post-monsoon season, whereas the lowest was recorded at site NE (1.25 ± 0.03 %) during the post-monsoon season. In Champhai, SOC ranged from 0.76 ± 0.10% to 2.92 ± 0.04%.The highest SOC was recorded at site KB (2.92 ± 0.04%) during the pre-monsoon season in the surface layer, whereas the lowest SOC was recorded at site KK (0.76 ± 0.10%) during the monsoon season in the subsurface layer.
13. The available nitrogen in Churachandpur ranged from 219.52 ± 36.21 kg/ha to 669.01 ± 20.91 kg/ha, with the maximum at site EP (669.01 ± 20.91 kg/ha) during the monsoon season in the surface layer and the minimum at site NE (219.52 ± 36.21 kg/ha) in the post-monsoon subsurface layer. In Champhai, available nitrogen ranged from 135.89 ± 10.45 kg/ha to 669.01 ± 20.91 kg/ha, with the maximum at site KB (669.01 ± 20.91 kg/ha) during the monsoon season in the surface layer and the minimum at site KK (135.89 ± 10.45 kg/ha) in the pre-monsoon subsurface layer.
14. Available phosphorus in Churachandpur varies from 18.1 ± 0.48 kg/ha to 38.1 ± 2.86 kg/ha, peaking at site HK (38.1 ± 2.86 kg/ha) during the monsoon season in the surface layer and reaching its minimum at site EP (18.1 ± 0.48 kg/ha) in the pre-monsoon subsurface layer. In Champhai, it ranges from 18.1 ± 0.48 kg/ha to 35.75 ± 1.16 kg/ha, with the highest value at site KB (35.75 ± 1.16 kg/ha) during the monsoon season in the surface layer and the lowest at site NE (18.1 ± 0.48 kg/ha) in the pre-monsoon subsurface layer.
15. Available potassium in Churachandpur ranges from 138.28 ± 1.16 kg/ha to 263.68 ± 1.76 kg/ha, with the highest value at site HK (263.68 ± 1.76 kg/ha) during the monsoon season in the surface layer and the lowest at site EP (138.28 ± 1.16 kg/ha) in the pre-monsoon subsurface layer. In Champhai, it varies from 138.28 ± 1.16 kg/ha to 248.14 ± 3.39 kg/ha, peaking at site NE (248.14 ± 3.39 kg/ha) during the monsoon season in the surface layer and reaching its minimum at site KK (138.28 ± 1.16 kg/ha) in the pre-monsoon subsurface layer.

16. Exchangeable sodium in Churachandpur ranges from 1.32 ± 0.02 to 1.79 ± 0.04 cmol(p^+)/kg. The highest Exch. Na was observed at site EP (1.79 ± 0.04 cmol(p^+)/kg) during the post-monsoon season in the subsurface layer, while the lowest was at site EP (1.32 ± 0.02 cmol(p^+)/kg) during the pre-monsoon season in the surface layer. In Champhai, Exch. Na varies from 1.32 ± 0.02 to 1.76 ± 0.01 cmol(p^+)/kg, with the maximum at site KK (1.76 ± 0.01 cmol(p^+)/kg) during the post-monsoon season in the subsurface layer and the minimum at site NE (1.32 ± 0.02 cmol(p^+)/kg) during the pre-monsoon season in the surface layer.
17. Exchangeable calcium in Churachandpur ranges from 0.53 ± 0.13 to 1.97 ± 0.03 cmol(p^+)/kg, with the maximum at site EP (1.97 ± 0.03 cmol(p^+)/kg) during the pre-monsoon season in the surface layer and the minimum at site EP (0.53 ± 0.13 cmol(p^+)/kg) in the pre-monsoon subsurface layer. In Champhai, Exch. Ca varies from 0.61 ± 0.09 to 1.97 ± 0.03 cmol(p^+)/kg, peaking at site KB (1.97 ± 0.03 cmol(p^+)/kg) during the pre-monsoon season in the surface layer and reaching its minimum at site KK (0.61 ± 0.09 cmol(p^+)/kg) in the pre-monsoon subsurface layer.
18. Exchangeable magnesium in Churachandpur varies from 0.95 ± 0.04 to 1.68 ± 0.03 cmol(p^+)/kg, with the highest value at site EP (1.68 ± 0.03 cmol(p^+)/kg) during the post-monsoon season in the surface layer and the lowest at site HK (0.95 ± 0.04 cmol(p^+)/kg) in the post-monsoon surface layer. In Champhai, Exch. Mg ranges from 0.95 ± 0.02 to 1.66 ± 0.04 cmol(p^+)/kg, with the maximum at site NE (1.66 ± 0.04 cmol(p^+)/kg) during the post-monsoon season in the subsurface layer and the minimum at site KB (0.95 ± 0.02 cmol(p^+)/kg) in the post-monsoon surface layer.
19. Both maize and cucumber cultivation appear to be profitable in both districts, with benefit-cost ratios consistently above two for maize and above three for cucumber. There was slight variation in input costs and outputs between sites, which may be due to local conditions or farming practices.
20. Cucumber cultivation shows higher profitability than maize in both districts, with higher benefit-cost ratios and absolute profit figures.
21. The profitability of both crops appeared to be relatively consistent across the two districts, suggesting that both Churachandpur and Champhai were suitable for maize and cucumber cultivation.

Recommendations

The following are some recommended management practices for promoting sustainable agro-ecological practices in Champhai, Mizoram, and Churachandpur, Manipur:

1) Implement soil and water conservation techniques such as contour bunding, terracing, and cover cropping to prevent erosion and nutrient loss. The construction of small earthen embankments along the contours of sloping lands can effectively reduce soil erosion and enhance water infiltration (Sharda et al., 2010). This helps to conserve precious topsoil and improve moisture availability for crops. The practice of creating flat-stepped sections on sloping lands can also mitigate erosion and improve water management (Tiwari et al., 2009). Terraced fields help slow down surface runoff and increase water retention. Cover cropping, the cultivation of plants primarily to protect and enrich the soil, can prevent nutrient loss and degradation. Cover crops such as legumes and grasses can fix nitrogen, improve soil organic matter, and suppress weeds (Feng et al., 2021).
2) Enrichment soil fertility through organic amendments, such as crop residues, green manure, and compost. Optimise fallow periods to allow nutrient replenishment. Incorporating organic amendments such as crop residues, green manure, and compost can improve soil fertility, structure, and water-holding capacity (Bhattacharyya et al., 2016). This helps to sustain long-term soil productivity. Optimising fallow periods when land is left uncultivated to allow for natural regeneration can facilitate the replenishment of soil nutrients and biodiversity (Wapongnungsang et al., 2021; Temjen et al., 2022). This is particularly relevant in the traditional jhum (shifting cultivation) systems. Legume-based green manures, such as *Mucuna pruriens* and *Crotalaria juncea*, can fix atmospheric nitrogen and enhance soil organic matter when incorporated into the soil (Meena et al., 2018).
3) Diversify cropping systems by integrating legumes, cash crops, horticultural crops, etc. to improve income. Diversified cropping systems, including the integration of legumes, cash crops, and horticultural crops, can improve income, nutritional security, and ecological resilience (Hufnagel et al., 2020; Riar et al., 2024). Legumes

such as pigeon peas, mung beans, and soybeans can fix atmospheric nitrogen, improve soil fertility, and provide protein-rich food and fodder (Yuvaraj, 2020; Kebede, 2021). Cash crops such as ginger, turmeric, and tea can enhance the economic viability of farming systems (Hashmiu, 2024), whereas horticultural crops, such as fruits and vegetables, can improve dietary diversity and nutritional intake (Marino, 2021; Rasu et al., 2023). Promoting crop diversification can also help mitigate the risks associated with monocultures, such as pest and disease outbreaks and climate-related stresses (Altieri et al., 2015).

4) Promote organic farming practices using biofertilizers and biopesticides to minimise external inputs. Organic farming, which relies on the use of organic amendments, biofertilizers, and biopesticides, can help reduce the dependence on synthetic fertilisers and pesticides, thereby minimising environmental degradation (Rajput et al., 2021; Akanmu et al., 2023; Ammar et al., 2023). Biofertilizers, such as Rhizobium, Azospirillum, and Azotobacter, can fix atmospheric nitrogen, solubilise phosphorus, and improve nutrient availability for crops (Mahanty et al., 2016; Chaudhary et al., 2022; Timofeeva et al., 2023). Biopesticides derived from natural sources such as plants, microbes, and beneficial insects can effectively manage pests and diseases in an eco-friendly manner (Lirikum et al., 2022). Promoting organic farming can also contribute to the conservation of biodiversity, soil health, and ecosystem services, while ensuring the production of safe and nutritious food (Joshi et al., 2020).

5) Strengthen extension services and farmer training on agro-ecological methods, and provide incentives for adopting sustainable practices. Strengthen extension services and farmer training on agro-ecological methods. The expansion and enhancement of agricultural extension services is pivotal for spreading knowledge and fostering the adoption of sustainable agro-ecological practices (Aich et al., 2022; Abhijeet et al. 2023; Awasthi et al., 2023). Comprehensive training initiatives for farmers, encompassing subjects such as organic farming, integrated pest management, and water conservation methods, can equip them to shift towards more sustainable practices (Gondwe et al., 2017; Xu et al., 2023). Offering incentives, including subsidies, low-interest loans, and market premiums for organic produce, can

motivate farmers to adopt sustainable practices and help balance their initial investment costs (Yang et al., 2023). Farmer field schools and demonstration plots can act as venues for experiential learning and peer-to-peer knowledge exchange among farmers (Tomlinson & Rhiney, 2017; van den Berg et al., 2020; Bakker et al., 2021).

6) Develop community institutions for collective resource management and equitable land allocation. Secure land tenure rights to encourage long-term investments. Strengthening community-based organisations, such as farmer cooperatives and self-help groups, can facilitate collective decision making, resource management, and equitable distribution of benefits (Eswarappa, 2020). Securing land tenure rights through formal titles or community-based tenure systems can provide farmers with confidence to invest in long-term sustainable practices such as agroforestry and soil conservation (Kotu et al., 2017). Promoting community-based institutions for the governance of common resources, such as forests and water bodies, can help prevent overexploitation and ensure sustainable utilisation (Salerno et al., 2021). Integrating traditional land allocation and management systems, such as those practiced in jhum cultivation, with modern sustainable practices can contribute to the preservation of local ecological knowledge and community-based resource management (Kerr, 2002).

7) Enhance market linkages, value addition, and non-farm income opportunities while preventing over-exploitation of resources. Improving market access and infrastructure, such as developing rural roads, storage facilities, and market information systems, can help farmers better sell their sustainable agricultural products (Xie et al., 2024). Facilitating value addition through the processing, packaging, and branding of organic and specialty crops can increase farmers' income and encourage the adoption of sustainable practices (Neema 2023). Promoting non-farm income opportunities, such as ecotourism, handicrafts, and small-scale enterprises, can diversify the rural economy and reduce the pressure on natural resources (Kumar et al., 2020). Implementing resource-use efficiency measures, such as water-saving technologies and sustainable energy sources, can help prevent the

overexploitation of natural resources, while enhancing the economic viability of farming systems (Ahmad & Dar, 2020).

8) Revive traditional ecological knowledge and practices related to jhum through community participation. Documenting and integrating traditional ecological knowledge and practices related to jhum can help sustain a region's ecological and cultural heritage (Dasgupta et al., 2021; Pandey et al., 2022). Engaging with local communities, especially indigenous groups, to understand and revive sustainable jhum practices, such as crop rotation, fallow periods, and forest management, can contribute to the preservation of agrobiodiversity and ecosystem services (Mertz et al., 2009). Promoting community-based monitoring and decision-making processes for the management of jhum lands can ensure equitable and sustainable utilisation of these resources (Kerr, 2002). Incorporating traditional jhum practices with modern sustainable techniques, such as agroforestry and soil conservation, can create a synergistic approach to address the environmental and livelihood challenges in the region (Dasgupta et al., 2021; Singh, 2022).

9) Promote integrated landscape-level planning and diversified farming system research tailored to local contexts. Adopting an integrated landscape approach that considers the interconnectedness of various land uses such as agriculture, forests, and water bodies can help develop holistic and context-specific solutions (Sayer et al., 2013). Conducting participatory research on diversified farming systems incorporating traditional and modern sustainable practices can generate location-specific recommendations that address the unique agro-ecological and socioeconomic conditions of the region (Altieri et al., 2015). Establishing collaborative platforms that bring together researchers, extension workers, policymakers, and local communities can facilitate the co-creation and implementation of sustainable land management strategies (Karrasch et al., 2017; Spina et al., 2023). Emphasising the role of traditional knowledge and practices, along with scientific innovations, can foster a synergistic approach to developing resilient and diversified farming systems (Hamadani et al., 2021; Mohan et al., 2021).

10) Formulate supportive policies and institutional mechanisms for officially recognising jhum cultivation. Developing policies that formally recognise and support the

sustainable practice of jhum (shifting cultivation) can help preserve traditional ecological knowledge and livelihoods (Datta et al., 2014; Singh, 2019). Establishing institutional mechanisms such as community-based management committees and advisory boards can facilitate the integration of jhum practices with modern sustainable farming approaches (Kerr, 2002). Providing financial and technical assistance, as well as secure land tenure rights, for jhum practitioners can encourage the adoption of sustainable practices and prevent the abandonment of traditional farming systems (UN-Habitat, 2018; Madusa et al., 2022). Incorporating traditional jhum cultivation into the broader framework of sustainable land management policies can help address the environmental and socioeconomic challenges faced by rural communities (Mertz et al., 2009).

11) Adopt an ecosystem approach to sustain productivity, food security, ecological resilience, and rural livelihoods. Implementing an ecosystem-based approach that recognises the interdependence of agricultural systems, natural resources, and human well-being can help develop integrated and holistic solutions (Millennium Ecosystem Assessment, 2005). Promoting agroecological practices that mimic natural ecosystems, such as diversified cropping systems, integrated pest management, and biodiversity conservation, can enhance ecosystem services and resilience (Altieri et al., 2015). Ensuring equitable access and sustainable management of common resources, such as forests, water bodies, and grazing lands, can contribute to the long-term sustainability of rural livelihoods and food security (FAO, IFAD, UN Women & WFP, 2023; Kumar, 2022; Woodhill et al., 2022).Adopting a landscape-level perspective that considers the interconnections between various land uses and stakeholders can facilitate co-creation of context-specific strategies for sustainable development (Sayer et al. 2013).

By implementing these comprehensive recommendations, the promotion of sustainable agro-ecological practices in the Champhai and Churachandpur districts can be enhanced, leading to improved environmental sustainability, food security, and livelihood opportunities for the local farming communities.

Appendix I. Pearson Correlation coefficients of soil parameters with altitude, depth and seasons (Churachandpur)

	A lt	p t	a s	a n	il	t a	p H	E C	M	H C	B D	O C	a il	a il	a il	h	h	h
Alt	1																	
Dept h	0	1																
Seas on	0	0	1															
Sand	-0.04	0	-.289*	1														
Silt	.318*	0.04	-0.16	-.831**	1													
Clay	-.510**	-0.07	.665**	0.14	-.669**	1												
pH	-0.08	-0.14	-	-	0.25	-	1											

			0.12	.288*		0.07												
EC	-0.18	-.609**	0.10	-.321**	0.14	0.19	.541**	1										
SMC	.691**	-0.16	-0.03	.328*	-0.07	-.321*	-.293*	-0.23	1									
WHC	0.08	-.537**	.589**	-0.03	-0.17	.339*	-0.08	0.22	.302*	1								
BD	-.430**	.491**	0.13	0.19	-.311*	.304*	-.509**	-.420**	-0.13	-0.26	1							
SOC	.521**	-0.24	0.01	-.329*	.425**	-.315*	.463**	.343*	.336*	0.26	-.583**	1						
Avail. N	-0.02	-.435**	.461**	-.375**	0.15	0.24	0.18	.499**	0.03	.642**	-.288*	.505**	1					

Avail. P	0.14	-.377**	0.24	.384**	-.382**	0.17	-0.13	0.05	.441**	.748**	-0.20	0.26	.452**	1				
Avail. K	.754**	-0.19	0.05	0.04	0.16	-.340*	-.430**	-0.16	.667**	0.10	-0.09	0.08	-0.08	0.03	1			
Exch. Na	-0.02	0.10	.828**	0.04	-.360**	.585**	-.461**	-0.18	0.19	.546**	.393**	-.274*	0.20	.323*	0.19	1		
Exch. Ca	-0.05	-.506**	-0.03	0.03	-0.13	0.19	0.25	.421**	-0.05	0.13	-.400**	0.21	0.13	0.09	-0.09	-0.20	1	
Exch. Mg	-0.12	.425**	-0.13	0.02	0.10	-0.20	-0.14	-.388**	-0.17	-.326*	.372**	-.296*	-.478**	-.365**	-0.04	-0.01	0	1

* and **. Correlation is significant at the 0.05 and 0.01 level (2-tailed).

Alt: altitude; EC: electrical conductivity (dSm^{-1}); SMC: soil moisture content (%); WHC: water-holding capacity (%); BD: bulk density (g/cm^3); SOC: organic carbon (%); Avail. N: available nitrogen (kg/ha); Avail. P: available phosphorus (kg/ha); Avail. K –

available potassium (kg/ha), Exch. Na – exchangeable sodium (cmol(p^+)/kg), Exch. Ca – exchangeable calcium (cmol(p^+)/kg), Exch. Mg – exchangeable magnesium (cmol(p^+)/kg)

Appendix II. Pearson Correlation coefficients of soil parameters with altitude, depth and seasons (Champhai)

Alt	1																	
Depth	0	1																
Seasons	0	0	1															
Sand	.302*	-0.01	-.396**	1														
Silt	-0.18	-0.02	0.20	-.870**	1													
Clay	-0.22	0.05	.348**	-0.15	-.352**	1												
SMC	.384*	-	-0.09	.417*	-	.296*	1											

	*	.521**		*	.543**													
WHC	.541**	-.360**	.582**	0.11	-0.23	0.25	.539**	1										
BD	-.916**	0.15	0.08	-0.17	-0.01	.342*	-.385**	-.440**	1									
pH	.369**	-.366**	-.303*	-0.14	.377**	-.481**	0.10	-0.03	-.555**	1								
EC	0.01	-.494**	-0.02	-.306*	.483**	-.377**	-0.02	0.03	-0.17	.596**	1							
SOC	.663**	-.533**	-0.19	0.22	-0.04	-.339*	.420**	.344*	-.727**	.643**	.423**	1						
Avail. N	.572**	-0.27	0.05	.608**	-.709*	.275*	.735**	.609**	-.389*	-0.04	-0.18	.416**	1					

					*				*									
Avail. P	.352**	-.302*	.340*	.351**	-.414**	0.16	.446**	.614**	-0.16	-.290*	-0.15	0.19	.712**	1				
Avail. K	.550**	-0.10	0.23	.430**	-.528**	0.24	.668**	.606**	-.474**	0.08	-0.12	.413**	.681**	.320*	1			
Exch. Na	0.01	0.04	.854**	-0.07	-0.19	.503**	0.09	.572**	0.16	-.569**	-.330*	-.286*	.305*	.598**	.294*	1		
Exch. Ca	0.24	-.603**	-0.09	0.12	-0.09	-0.03	.287*	0.25	-.333*	.468**	.364**	.534**	0.26	0.15	0.11	-0.12	1	
Exch. Mg	-0.06	0.14	0.02	0.22	-0.19	-0.04	-0.09	0.01	0.02	0.23	0.01	0.01	-0.06	-.389**	0.26	-0.08	0.12	1

* and **. Correlation is significant at the 0.05 and 0.01 level (2-tailed).

Alt: altitude; EC: electrical conductivity (dSm^{-1}); SMC: soil moisture content (%); WHC: water-holding capacity (%); BD: bulk density (g/cm^3); SOC: soil organic carbon (%); Avail. N: available nitrogen (kg/ha); Avail. P: available phosphorus (kg/ha); Avail. K – available potassium (kg/ha), Exch. Na – exchangeable sodium ($cmol(p^+)/kg$), Exch. Ca – exchangeable calcium ($cmol(p^+)/kg$), Exch. Mg – exchangeable magnesium ($cmol(p^+)/kg$)

Appendix III. ANOVA for soil parameters across different altitudes (Churachandpur)

		Sum of Squares	df	Mean Square	F	Sig.
Sand (%)	Between Groups	29.73	2	14.86	0.33	0.72
	Within Groups	2326.24	51	45.61		
	Total	2355.97	53			
Silt (%)	Between Groups	454.68	2	227.34	3.11	0.05
	Within Groups	3724.73	51	73.03		
	Total	4179.41	53			
Clay (%)	Between Groups	344.15	2	172.08	8.97	0.00
	Within Groups	978.11	51	19.18		
	Total	1322.27	53			
SMC (%)	Between Groups	204.85	2	102.43	23.44	0.00
	Within Groups	222.86	51	4.37		
	Total	427.71	53			
WHC (%)	Between Groups	58.44	2	29.22	3.02	0.06
	Within Groups	493.57	51	9.68		
	Total	552.02	53			
Bulk	Between	0.21	2	0.11	12.11	0.00

Density (g/cm^3)	Groups					
	Within Groups	0.45	51	0.01		
	Total	0.66	53			
pH	Between Groups	1.80	2	0.90	6.67	0.00
	Within Groups	6.88	51	0.13		
	Total	8.68	53			
EC	Between Groups	0.01	2	0.00	1.48	0.24
	Within Groups	0.13	51	0.00		
	Total	0.13	53			
SOC (%)	Between Groups	8.23	2	4.11	36.15	0.00
	Within Groups	5.80	51	0.11		
	Total	14.03	53			
Avail. N (kg/ha)	Between Groups	93136.32	2	46568.16	4.42	0.02
	Within Groups	537892.30	51	10546.91		
	Total	631028.61	53			
Avail. P (kg/ha)	Between Groups	519.34	2	259.67	11.42	0.00
	Within Groups	1159.43	51	22.73		
	Total	1678.77	53			
Avail. K	Between	66927.41	2	33463.70	170.53	0.00

(kg/ha)	Groups					
	Within Groups	10007.82	51	196.23		
	Total	76935.23	53			
Exch. Na $cmol(p^+)/kg$	Between Groups	0.04	2	0.02	0.62	0.54
	Within Groups	1.58	51	0.03		
	Total	1.62	53			
Exch. Ca $cmol(p^+)/kg$	Between Groups	0.13	2	0.07	0.29	0.75
	Within Groups	11.83	51	0.23		
	Total	11.96	53			
Exch. Mg $cmol(p^+)/kg$	Between Groups	0.30	2	0.15	3.66	0.03
	Within Groups	2.12	51	0.04		
	Total	2.42	53			

Appendix IV. ANOVA for soil parameters across seasons (Churachandpur)

		Sum of Squares	df	Mean Square	F	Sig.
Sand (%)	Between Groups	1477.96	2	738.98	42.92	0.00
	Within Groups	878.01	51	17.22		
	Total	2355.97	53			
Silt (%)	Between Groups	1728.95	2	864.47	17.99	0.00
	Within Groups	2450.46	51	48.05		
	Total	4179.41	53			
Clay (%)	Between Groups	604.88	2	302.44	21.50	0.00
	Within Groups	717.39	51	14.07		
	Total	1322.27	53			
SMC (%)	Between Groups	96.59	2	48.30	7.44	0.00
	Within Groups	331.12	51	6.49		
	Total	427.71	53			
WHC (%)	Between Groups	253.99	2	126.99	21.73	0.00
	Within Groups	298.03	51	5.84		
	Total	552.02	53			
BD (g/cm^3)	Between Groups	0.08	2	0.04	3.34	0.04

	Within Groups	0.59	51	0.01		
	Total	0.66	53			
pH	Between Groups	3.32	2	1.66	15.82	0.00
	Within Groups	5.36	51	0.11		
	Total	8.68	53			
EC (dSm^{-1})	Between Groups	0.03	2	0.01	6.75	0.00
	Within Groups	0.11	51	0.00		
	Total	0.13	53			
SOC (%)	Between Groups	2.22	2	1.11	4.79	0.01
	Within Groups	11.81	51	0.23		
	Total	14.03	53			
Avail. N (kg/ha)	Between Groups	140014.08	2	70007.04	7.27	0.00
	Within Groups	491014.53	51	9627.74		
	Total	631028.61	53			
Avail. P (kg/ha)	Between Groups	746.16	2	373.08	20.40	0.00
	Within Groups	932.61	51	18.29		
	Total	1678.77	53			
Avail. K (kg/ha)	Between Groups	3878.81	2	1939.41	1.35	0.27

	Within Groups	73056.42	51	1432.48		
	Total	76935.23	53			
Exch. Na $cmol(p^{+})/kg$	Between Groups	1.41	2	0.70	170.39	0.00
	Within Groups	0.21	51	0.00		
	Total	1.62	53			
Exch. Ca $cmol(p^{+})/kg$	Between Groups	0.51	2	0.25	1.12	0.33
	Within Groups	11.45	51	0.22		
	Total	11.96	53			
Exch. Mg $cmol(p^{+})/kg$	Between Groups	0.04	2	0.02	0.43	0.65
	Within Groups	2.38	51	0.05		
	Total	2.42	53			

Appendix V. LSD post-hoc tests for soil parameters across altitude (Churachandpur)

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Sand (%)	491	987	1.7983*	0.05	0.00	1.69	1.90
		1430	.6717*	0.05	0.00	0.57	0.78
	987	491	-1.7983*	0.05	0.00	-1.90	-1.69
		1430	-1.1267*	0.05	0.00	-1.23	-1.02
	1430	491	-.6717*	0.05	0.00	-0.78	-0.57
		987	1.1267*	0.05	0.00	1.02	1.23
Silt (%)	491	987	-5.0617*	0.09	0.00	-5.24	-4.89
		1430	-6.8522*	0.09	0.00	-7.03	-6.68
	987	491	5.0617*	0.09	0.00	4.89	5.24
		1430	-1.7906*	0.09	0.00	-1.97	-1.62
	1430	491	6.8522*	0.09	0.00	6.68	7.03
		987	1.7906*	0.09	0.00	1.62	1.97
Clay (%)	491	987	3.2633*	0.07	0.00	3.11	3.41
		1430	6.1806*	0.07	0.00	6.03	6.33
	987	491	-3.2633*	0.07	0.00	-3.41	-3.11
		1430	2.9172*	0.07	0.00	2.77	3.07
	1430	491	-6.1806*	0.07	0.00	-6.33	-6.03
		987	-2.9172*	0.07	0.00	-3.07	-2.77
SMC (%)	491	987	-2.1872*	0.34	0.00	-2.88	-1.49
		1430	-4.7656*	0.34	0.00	-5.46	-4.07
	987	491	2.1872*	0.34	0.00	1.49	2.88
		1430	-2.5783*	0.34	0.00	-3.27	-1.88
	1430	491	4.7656*	0.34	0.00	4.07	5.46
		987	2.5783*	0.34	0.00	1.88	3.27
WHC (%)	491	987	1.8278*	0.09	0.00	1.65	2.01

		1430	-.6239*	0.09	0.00	-0.80	-0.44
	987	491	-1.8278*	0.09	0.00	-2.01	-1.65
		1430	-2.4517*	0.09	0.00	-2.63	-2.27
	1430	491	.6239*	0.09	0.00	0.44	0.80
		987	2.4517*	0.09	0.00	2.27	2.63
BD (g/cm^3)	491	987	-.0289*	0.01	0.05	-0.06	0.00
		1430	.1167*	0.01	0.00	0.09	0.15
	987	491	.0289*	0.01	0.05	0.00	0.06
		1430	.1456*	0.01	0.00	0.12	0.17
	1430	491	-.1167*	0.01	0.00	-0.15	-0.09
		987	-.1456*	0.01	0.00	-0.17	-0.12
pH	491	987	.4206*	0.09	0.00	0.25	0.59
		1430	0.08	0.09	0.36	-0.09	0.25
	987	491	-.4206*	0.09	0.00	-0.59	-0.25
		1430	-.3417*	0.09	0.00	-0.51	-0.17
	1430	491	-0.08	0.09	0.36	-0.25	0.09
		987	.3417*	0.09	0.00	0.17	0.51
EC (dSm^{-1})	491	987	.0267*	0.01	0.02	0.00	0.05
		1430	0.02	0.01	0.05	0.00	0.04
	987	491	-.0267*	0.01	0.02	-0.05	0.00
		1430	0.00	0.01	0.69	-0.03	0.02
	1430	491	-0.02	0.01	0.05	-0.04	0.00
		987	0.00	0.01	0.69	-0.02	0.03
SOC (%)	491	987	.2822*	0.04	0.00	0.19	0.37
		1430	-.6500*	0.04	0.00	-0.74	-0.56
	987	491	-.2822*	0.04	0.00	-0.37	-0.19
		1430	-.9322*	0.04	0.00	-1.02	-0.84
	1430	491	.6500*	0.04	0.00	0.56	0.74
		987	.9322*	0.04	0.00	0.84	1.02
Avail. N	491	987	90.5956*	8.77	0.00	72.81	108.38

(kg/ha)		1430	5.23	8.77	0.55	-12.56	23.01
	987	491	-90.5956*	8.77	0.00	-108.38	-72.81
		1430	-85.3689*	8.77	0.00	-103.15	-67.58
	1430	491	-5.23	8.77	0.55	-23.01	12.56
		987	85.3689*	8.77	0.00	67.58	103.15
Avail. P (kg/ha)	491	987	5.4256*	0.62	0.00	4.17	6.68
		1430	-1.8917*	0.62	0.00	-3.15	-0.64
	987	491	-5.4256*	0.62	0.00	-6.68	-4.17
		1430	-7.3172*	0.62	0.00	-8.57	-6.06
	1430	491	1.8917*	0.62	0.00	0.64	3.15
		987	7.3172*	0.62	0.00	6.06	8.57
Avail. K (kg/ha)	491	987	-78.7972*	1.23	0.00	-81.30	-76.30
		1430	-69.7389*	1.23	0.00	-72.24	-67.24
	987	491	78.7972*	1.23	0.00	76.30	81.30
		1430	9.0583*	1.23	0.00	6.56	11.56
	1430	491	69.7389*	1.23	0.00	67.24	72.24
		987	-9.0583*	1.23	0.00	-11.56	-6.56
Exch. Na cmol(p^+)/kg	491	987	-.0511*	0.02	0.01	-0.09	-0.01
		1430	0.01	0.02	0.59	-0.03	0.05
	987	491	.0511*	0.02	0.01	0.01	0.09
		1430	.0611*	0.02	0.00	0.02	0.10
	1430	491	-0.01	0.02	0.59	-0.05	0.03
		987	-.0611*	0.02	0.00	-0.10	-0.02
Exch. Ca cmol(p^+)/kg	491	987	.1211*	0.06	0.04	0.00	0.24
		1430	0.05	0.06	0.35	-0.06	0.17
	987	491	-.1211*	0.06	0.04	-0.24	0.00
		1430	-0.07	0.06	0.26	-0.18	0.05
	1430	491	-0.05	0.06	0.35	-0.17	0.06
		987	0.07	0.06	0.26	-0.05	0.18
Exch. Mg	491	987	-.1194*	0.03	0.00	-0.18	-0.06

cmol(p^+)/kg		1430	.0611*	0.03	0.04	0.00	0.12
	987	491	.1194*	0.03	0.00	0.06	0.18
		1430	.1806*	0.03	0.00	0.12	0.24
	1430	491	-.0611*	0.03	0.04	-0.12	0.00
		987	-.1806*	0.03	0.00	-0.24	-0.12

Based on observed means.

The error term is Mean Square (Error) = .008.

*. The mean difference is significant at the .05 level.

491 – site KG, 987 – site EP, 1430 – site HK

Appendix VI. LSD post-hoc test for soil parameters across seasons (Churachandpur)

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Sand (%)	Pre-monsoon	Monsoon	-7.9983*	0.05	0.00	-8.10	-7.89
		Post monsoon	4.6717*	0.05	0.00	4.57	4.78
	Monsoon	Pre-monsoon	7.9983*	0.05	0.00	7.89	8.10
		Post monsoon	12.6700*	0.05	0.00	12.57	12.77
	Post monsoon	Pre-monsoon	-4.6717*	0.05	0.00	-4.78	-4.57
		Monsoon	-12.6700*	0.05	0.00	-12.77	-12.57
Silt (%)	Pre-monsoon	Monsoon	13.3328*	0.09	0.00	13.16	13.51
		Post monsoon	3.3867*	0.09	0.00	3.21	3.56
	Monsoon	Pre-monsoon	-13.3328*	0.09	0.00	-13.51	-13.16
		Post monsoon	-9.9461*	0.09	0.00	-10.12	-9.77
	Post monsoon	Pre-monsoon	-3.3867*	0.09	0.00	-3.56	-3.21
		Monsoon	9.9461*	0.09	0.00	9.77	10.12
Clay (%)	Pre-monsoon	Monsoon	-5.3344*	0.07	0.00	-5.48	-5.19
		Post monsoon	-8.0583*	0.07	0.00	-8.21	-7.91
	Monsoon	Pre-monsoon	5.3344*	0.07	0.00	5.19	5.48

		Post monsoon	-2.7239*	0.07	0.00	-2.87	-2.57
	Post monsoon	Pre-monsoon	8.0583*	0.07	0.00	7.91	8.21
		Monsoon	2.7239*	0.07	0.00	2.57	2.87
SMC (%)	Pre-monsoon	Monsoon	-2.7422*	0.34	0.00	-3.44	-2.05
		Post monsoon	0.18	0.34	0.60	-0.52	0.88
	Monsoon	Pre-monsoon	2.7422*	0.34	0.00	2.05	3.44
		Post monsoon	2.9233*	0.34	0.00	2.23	3.62
	Post monsoon	Pre-monsoon	-0.18	0.34	0.60	-0.88	0.52
		Monsoon	-2.9233*	0.34	0.00	-3.62	-2.23
WHC (%)	Pre-monsoon	Monsoon	-4.5883*	0.09	0.00	-4.77	-4.41
		Post monsoon	-4.6128*	0.09	0.00	-4.79	-4.43
	Monsoon	Pre-monsoon	4.5883*	0.09	0.00	4.41	4.77
		Post monsoon	-0.02	0.09	0.79	-0.21	0.16
	Post monsoon	Pre-monsoon	4.6128*	0.09	0.00	4.43	4.79
		Monsoon	0.02	0.09	0.79	-0.16	0.21
BD (g/cm^3)	Pre-monsoon	Monsoon	-.0917*	0.01	0.00	-0.12	-0.06
		Post monsoon	-.0356*	0.01	0.02	-0.06	-0.01
	Monsoon	Pre-monsoon	.0917*	0.01	0.00	0.06	0.12

		Post monsoon	.0561*	0.01	0.00	0.03	0.08
	Post monsoon	Pre-monsoon	.0356*	0.01	0.02	0.01	0.06
		Monsoon	-.0561*	0.01	0.00	-0.08	-0.03
pH	Pre-monsoon	Monsoon	.5756*	0.09	0.00	0.40	0.75
		Post monsoon	0.12	0.09	0.17	-0.05	0.29
	Monsoon	Pre-monsoon	-.5756*	0.09	0.00	-0.75	-0.40
		Post monsoon	-.4567*	0.09	0.00	-0.63	-0.28
	Post monsoon	Pre-monsoon	-0.12	0.09	0.17	-0.29	0.05
		Monsoon	.4567*	0.09	0.00	0.28	0.63
EC (dSm^{-1})	Pre-monsoon	Monsoon	.0411*	0.01	0.00	0.02	0.06
		Post monsoon	-0.01	0.01	0.28	-0.03	0.01
	Monsoon	Pre-monsoon	-.0411*	0.01	0.00	-0.06	-0.02
		Post monsoon	-.0533*	0.01	0.00	-0.08	-0.03
	Post monsoon	Pre-monsoon	0.01	0.01	0.28	-0.01	0.03
		Monsoon	.0533*	0.01	0.00	0.03	0.08
SOC (%)	Pre-monsoon	Monsoon	.4239*	0.04	0.00	0.33	0.51
		Post monsoon	-0.01	0.04	0.79	-0.10	0.08
	Monsoon	Pre-monsoon	-.4239*	0.04	0.00	-0.51	-0.33

		Post monsoon	-.4356*	0.04	0.00	-0.53	-0.35
	Post monsoon	Pre-monsoon	0.01	0.04	0.79	-0.08	0.10
		Monsoon	.4356*	0.04	0.00	0.35	0.53
Avail. N (kg/ha)	Pre-monsoon	Monsoon	-38.3289*	8.77	0.00	-56.11	-20.54
		Post monsoon	-121.9556*	8.77	0.00	-139.74	-104.17
	Monsoon	Pre-monsoon	38.3289*	8.77	0.00	20.54	56.11
		Post monsoon	-83.6267*	8.77	0.00	-101.41	-65.84
	Post monsoon	Pre-monsoon	121.9556*	8.77	0.00	104.17	139.74
		Monsoon	83.6267*	8.77	0.00	65.84	101.41
Avail. P (kg/ha)	Pre-monsoon	Monsoon	-8.9906*	0.62	0.00	-10.25	-7.73
		Post monsoon	-3.2472*	0.62	0.00	-4.50	-1.99
	Monsoon	Pre-monsoon	8.9906*	0.62	0.00	7.73	10.25
		Post monsoon	5.7433*	0.62	0.00	4.49	7.00
	Post monsoon	Pre-monsoon	3.2472*	0.62	0.00	1.99	4.50
		Monsoon	-5.7433*	0.62	0.00	-7.00	-4.49
Avail. K (kg/ha)	Pre-monsoon	Monsoon	-19.9328*	1.23	0.00	-22.43	-17.43
		Post monsoon	-4.9417*	1.23	0.00	-7.44	-2.44
	Monsoon	Pre-monsoon	19.9328*	1.23	0.00	17.43	22.43

		Post monsoon	14.9911*	1.23	0.00	12.49	17.49
	Post monsoon	Pre-monsoon	4.9417*	1.23	0.00	2.44	7.44
		Monsoon	-14.9911*	1.23	0.00	-17.49	-12.49
Exch. Na cmol(p+)/kg	Pre-monsoon	Monsoon	-.3333*	0.02	0.00	-0.37	-0.30
		Post monsoon	-.3511*	0.02	0.00	-0.39	-0.31
	Monsoon	Pre-monsoon	.3333*	0.02	0.00	0.30	0.37
		Post monsoon	-0.02	0.02	0.34	-0.06	0.02
	Post monsoon	Pre-monsoon	.3511*	0.02	0.00	0.31	0.39
		Monsoon	0.02	0.02	0.34	-0.02	0.06
Exch. Ca cmol(p+)/kg	Pre-monsoon	Monsoon	.2200*	0.06	0.00	0.10	0.34
		Post monsoon	0.03	0.06	0.56	-0.08	0.15
	Monsoon	Pre-monsoon	-.2200*	0.06	0.00	-0.34	-0.10
		Post monsoon	-.1861*	0.06	0.00	-0.30	-0.07
	Post monsoon	Pre-monsoon	-0.03	0.06	0.56	-0.15	0.08
		Monsoon	.1861*	0.06	0.00	0.07	0.30
Exch. Mg cmol(p+)/kg	Pre-monsoon	Monsoon	0.04	0.03	0.15	-0.02	0.10
		Post monsoon	.0656*	0.03	0.03	0.01	0.13
	Monsoon	Pre-monsoon	-0.04	0.03	0.15	-0.10	0.02

	Post monsoon	0.02	0.03	0.44	-0.04	0.08
Post monsoon	Pre-monsoon	-.0656*	0.03	0.03	-0.13	-0.01
	Monsoon	-0.02	0.03	0.44	-0.08	0.04

Based on observed means.

The error term is Mean Square (Error) = .008.

*. The mean difference is significant at the .05 level.

Appendix VII. ANOVA for soil parameters across different altitudes (Champhai)

		Sum of Squares	df	Mean Square	F	Sig.
Sand (%)	**Between Groups**	381.77	2.00	190.89	5.00	0.01
	Within Groups	1946.33	51.00	38.16		
	Total	2328.10	53.00			
Silt (%)	Between Groups	321.27	2.00	160.64	3.60	0.03
	Within Groups	2274.13	51.00	44.59		
	Total	2595.40	53.00			
Clay (%)	Between Groups	36.13	2.00	18.06	1.53	0.23
	Within Groups	602.74	51.00	11.82		
	Total	638.86	53.00			
pH	Between Groups	0.35	2.00	0.18	4.25	0.02
	Within Groups	2.12	51.00	0.04		
	Total	2.48	53.00			
EC (dSm^{-1})	Between Groups	0.00	2.00	0.00	0.00	1.00
	Within Groups	0.15	51.00	0.00		
	Total	0.15	53.00			
SMC (%)	Between Groups	193.76	2.00	96.88	8.23	0.00

	Within Groups	600.68	51.00	11.78		
	Total	794.45	53.00			
WHC (%)	Between Groups	192.56	2.00	96.28	11.15	0.00
	Within Groups	440.25	51.00	8.63		
	Total	632.81	53.00			
BD (g/cm^3)	Between Groups	1.46	2.00	0.73	140.24	0.00
	Within Groups	0.27	51.00	0.01		
	Total	1.73	53.00			
SOC (%)	Between Groups	11.43	2.00	5.72	21.18	0.00
	Within Groups	13.77	51.00	0.27		
	Total	25.20	53.00			
Avail. N (kg/ha)	Between Groups	386431.01	2.00	193215.51	12.62	0.00
	Within Groups	780615.02	51.00	15306.18		
	Total	1167046.03	53.00			
Avail. P (kg/ha)	Between Groups	351.53	2.00	175.76	9.37	0.00
	Within Groups	956.48	51.00	18.75		
	Total	1308.01	53.00			
Avail. K (kg/ha)	Between Groups	36728.33	2.00	18364.17	51.20	0.00

	Within Groups	18291.61	51.00	358.66		
	Total	55019.94	53.00			
Exch. Na (cmol(p^+)/kg)	Between Groups	0.01	2.00	0.01	0.24	0.79
	Within Groups	1.40	51.00	0.03		
	Total	1.42	53.00			
Exch. Ca (cmol(p^+)/kg)	Between Groups	0.52	2.00	0.26	1.68	0.20
	Within Groups	7.86	51.00	0.15		
	Total	8.38	53.00			
Exch. Mg (cmol(p^+)/kg)	Between Groups	0.64	2.00	0.32	12.74	0.00
	Within Groups	1.28	51.00	0.03		
	Total	1.92	53.00			

Appendix VIII. ANOVA for soil parameters across different seasons (Champhai)

		Sum of Squares	df	Mean Square	F	Sig.
Sand (%)	Between Groups	1300.87	2.00	650.43	32.29	0.00
	Within Groups	1027.23	51.00	20.14		
	Total	2328.10	53.00			
Silt (%)	Between Groups	1988.04	2.00	994.02	83.47	0.00
	Within Groups	607.36	51.00	11.91		
	Total	2595.40	53.00			
Clay (%)	Between Groups	241.38	2.00	120.69	15.49	0.00
	Within Groups	397.48	51.00	7.79		
	Total	638.86	53.00			
pH	Between Groups	1.22	2.00	0.61	24.95	0.00
	Within Groups	1.25	51.00	0.02		
	Total	2.48	53.00			
EC (dSm^{-1})	Between Groups	0.05	2.00	0.02	11.68	0.00
	Within Groups	0.10	51.00	0.00		
	Total	0.15	53.00			
SMC (%)	Between Groups	197.75	2.00	98.87	8.45	0.00

	Within Groups	596.70	51.00	11.70		
	Total	794.45	53.00			
WHC (%)	Between Groups	249.64	2.00	124.82	16.61	0.00
	Within Groups	383.17	51.00	7.51		
	Total	632.81	53.00			
BD (g/cm^3)	Between Groups	0.09	2.00	0.05	1.46	0.24
	Within Groups	1.63	51.00	0.03		
	Total	1.73	53.00			
SOC (%)	Between Groups	1.65	2.00	0.83	1.79	0.18
	Within Groups	23.55	51.00	0.46		
	Total	25.20	53.00			
Avail. N (kg/ha)	Between Groups	504116.03	2.00	252058.02	19.39	0.00
	Within Groups	662930.00	51.00	12998.63		
	Total	1167046.03	53.00			
Avail. P (kg/ha)	Between Groups	674.55	2.00	337.27	27.15	0.00
	Within Groups	633.46	51.00	12.42		
	Total	1308.01	53.00			
Avail. K (kg/ha)	Between Groups	10644.87	2.00	5322.43	6.12	0.00

	Within Groups	44375.08	51.00	870.10		
	Total	55019.94	53.00			
Exch. Na ($cmol(p^+)/kg$)	Between Groups	1.33	2.00	0.67	395.62	0.00
	Within Groups	0.09	51.00	0.00		
	Total	1.42	53.00			
Exch. Ca ($cmol(p^+)/kg$)	Between Groups	0.11	2.00	0.05	0.33	0.72
	Within Groups	8.28	51.00	0.16		
	Total	8.38	53.00			
Exch. Mg ($cmol(p^+)/kg$)	Between Groups	0.05	2.00	0.03	0.69	0.51
	Within Groups	1.87	51.00	0.04		
	Total	1.92	53.00			

Appendix IX. LSD post-hoc test for soil parameters across altitude (Champhai)

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Sand (%)	344	829	-6.1839*	0.11	0.00	-6.40	-5.96
		1579	-4.8622*	0.11	0.00	-5.08	-4.64
	829	344	6.1839*	0.11	0.00	5.96	6.40
		1579	1.3217*	0.11	0.00	1.10	1.54
	1579	344	4.8622*	0.11	0.00	4.64	5.08
		829	-1.3217*	0.11	0.00	-1.54	-1.10
Silt (%)	344	829	5.9744*	0.10	0.00	5.77	6.18
		1579	3.0356*	0.10	0.00	2.83	3.24
	829	344	-5.9744*	0.10	0.00	-6.18	-5.77
		1579	-2.9389*	0.10	0.00	-3.14	-2.74
	1579	344	-3.0356*	0.10	0.00	-3.24	-2.83
		829	2.9389*	0.10	0.00	2.74	3.14
Clay (%)	344	829	.2156*	0.06	0.00	0.09	0.34
		1579	1.8328*	0.06	0.00	1.71	1.96
	829	344	-.2156*	0.06	0.00	-0.34	-0.09
		1579	1.6172*	0.06	0.00	1.49	1.74
	1579	344	-1.8328*	0.06	0.00	-1.96	-1.71
		829	-1.6172*	0.06	0.00	-1.74	-1.49
pH	344	829	-.1350*	0.02	0.00	-0.18	-0.09
		1579	-.1933*	0.02	0.00	-0.24	-0.15
	829	344	.1350*	0.02	0.00	0.09	0.18
		1579	-.0583*	0.02	0.01	-0.10	-0.01
	1579	344	.1933*	0.02	0.00	0.15	0.24
		829	.0583*	0.02	0.01	0.01	0.10
EC (dSm^{-1})	344	829	0.00	0.01	0.97	-0.03	0.03

		1579	0.00	0.01	0.90	-0.03	0.03
	829	344	0.00	0.01	0.97	-0.03	0.03
		1579	0.00	0.01	0.93	-0.03	0.03
	1579	344	0.00	0.01	0.90	-0.03	0.03
		829	0.00	0.01	0.93	-0.03	0.03
SMC (%)	344	829	-4.3294*	0.41	0.00	-5.15	-3.51
		1579	-3.6100*	0.41	0.00	-4.43	-2.79
	829	344	4.3294*	0.41	0.00	3.51	5.15
		1579	0.72	0.41	0.09	-0.10	1.54
	1579	344	3.6100*	0.41	0.00	2.79	4.43
		829	-0.72	0.41	0.09	-1.54	0.10
WHC (%)	344	829	-3.0344*	0.23	0.00	-3.51	-2.56
		1579	-4.5406*	0.23	0.00	-5.02	-4.07
	829	344	3.0344*	0.23	0.00	2.56	3.51
		1579	-1.5061*	0.23	0.00	-1.98	-1.03
	1579	344	4.5406*	0.23	0.00	4.07	5.02
		829	1.5061*	0.23	0.00	1.03	1.98
BD (g/cm^3)	344	829	.2344*	0.02	0.00	0.20	0.27
		1579	.4011*	0.02	0.00	0.37	0.44
	829	344	-.2344*	0.02	0.00	-0.27	-0.20
		1579	.1667*	0.02	0.00	0.13	0.20
	1579	344	-.4011*	0.02	0.00	-0.44	-0.37
		829	-.1667*	0.02	0.00	-0.20	-0.13
SOC (%)	344	829	-.7272*	0.07	0.00	-0.87	-0.58
		1579	-1.1094*	0.07	0.00	-1.26	-0.96
	829	344	.7272*	0.07	0.00	0.58	0.87
		1579	-.3822*	0.07	0.00	-0.53	-0.24
	1579	344	1.1094*	0.07	0.00	0.96	1.26
		829	.3822*	0.07	0.00	0.24	0.53
Avail. N	344	829	-122.3800*	12.85	0.00	-148.44	-96.32

(kg/ha)		1579	-206.0000*	12.85	0.00	-232.06	-179.94
	829	344	122.3800*	12.85	0.00	96.32	148.44
		1579	-83.6200*	12.85	0.00	-109.68	-57.56
	1579	344	206.0000*	12.85	0.00	179.94	232.06
		829	83.6200*	12.85	0.00	57.56	109.68
Avail. P (kg/ha)	344	829	1.8556*	0.49	0.00	0.87	2.84
		1579	-4.2406*	0.49	0.00	-5.23	-3.25
	829	344	-1.8556*	0.49	0.00	-2.84	-0.87
		1579	-6.0961*	0.49	0.00	-7.09	-5.11
	1579	344	4.2406*	0.49	0.00	3.25	5.23
		829	6.0961*	0.49	0.00	5.11	7.09
Avail. K (kg/ha)	344	829	-62.4212*	1.29	0.00	-65.03	-59.81
		1579	-42.9744*	1.29	0.00	-45.58	-40.37
	829	344	62.4212*	1.29	0.00	59.81	65.03
		1579	19.4468*	1.29	0.00	16.84	22.05
	1579	344	42.9744*	1.29	0.00	40.37	45.58
		829	-19.4468*	1.29	0.00	-22.05	-16.84
Exch. Na (cmol(p^+)/kg)	344	829	.0306*	0.01	0.00	0.01	0.05
		1579	0.00	0.01	0.59	-0.02	0.01
	829	344	-.0306*	0.01	0.00	-0.05	-0.01
		1579	-.0356*	0.01	0.00	-0.05	-0.02
	1579	344	0.00	0.01	0.59	-0.01	0.02
		829	.0356*	0.01	0.00	0.02	0.05
Exch. Ca (cmol(p^+)/kg)	344	829	-0.06	0.03	0.05	-0.12	0.00
		1579	-.2306*	0.03	0.00	-0.29	-0.17
	829	344	0.06	0.03	0.05	0.00	0.12
		1579	-.1728*	0.03	0.00	-0.23	-0.11
	1579	344	.2306*	0.03	0.00	0.17	0.29
		829	.1728*	0.03	0.00	0.11	0.23
Exch. Mg	344	829	-.2156*	0.02	0.00	-0.25	-0.18

(cmol(p^+)/kg)		1579	0.03	0.02	0.10	-0.01	0.06
	829	344	.2156*	0.02	0.00	0.18	0.25
		1579	.2439*	0.02	0.00	0.21	0.28
	1579	344	-0.03	0.02	0.10	-0.06	0.01
		829	-.2439*	0.02	0.00	-0.28	-0.21

The error term is Mean Square (Error) = .003.

*. The mean difference is significant at the .05 level.

344 – site KK, 829 – site NE, 1579 – site KB

Appendix X. LSD post-hoc test for soil parameters across seasons (Champhai)

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Sand (%)	Pre-monsoon	Monsoon	-5.6533*	0.11	0.00	-5.87	-5.43
		Post monsoon	6.3622*	0.11	0.00	6.14	6.58
	Monsoon	Pre-monsoon	5.6533*	0.11	0.00	5.43	5.87
		Post monsoon	12.0156*	0.11	0.00	11.79	12.24
	Post monsoon	Pre-monsoon	-6.3622*	0.11	0.00	-6.58	-6.14
		Monsoon	-12.0156*	0.11	0.00	-12.24	-11.79
Silt (%)	Pre-monsoon	Monsoon	10.8100*	0.10	0.00	10.61	11.01
		Post monsoon	-3.4283*	0.10	0.00	-3.63	-3.23
	Monsoon	Pre-monsoon	-10.8100*	0.10	0.00	-11.01	-10.61
		Post monsoon	-14.2383*	0.10	0.00	-14.44	-14.04
	Post monsoon	Pre-monsoon	3.4283*	0.10	0.00	3.23	3.63
		Monsoon	14.2383*	0.10	0.00	14.04	14.44

Clay (%)	Pre-monsoon	Monsoon	-5.1628*	0.06	0.00	-5.29	-5.04
		Post monsoon	-2.9339*	0.06	0.00	-3.06	-2.81
	Monsoon	Pre-monsoon	5.1628*	0.06	0.00	5.04	5.29
		Post monsoon	2.2289*	0.06	0.00	2.10	2.35
	Post monsoon	Pre-monsoon	2.9339*	0.06	0.00	2.81	3.06
		Monsoon	-2.2289*	0.06	0.00	-2.35	-2.10
pH	Pre-monsoon	Monsoon	.3678*	0.02	0.00	0.32	0.41
		Post monsoon	.1589*	0.02	0.00	0.11	0.20
	Monsoon	Pre-monsoon	-.3678*	0.02	0.00	-0.41	-0.32
		Post monsoon	-.2089*	0.02	0.00	-0.25	-0.16
	Post monsoon	Pre-monsoon	-.1589*	0.02	0.00	-0.20	-0.11
		Monsoon	.2089*	0.02	0.00	0.16	0.25
EC (dSm^{-1})	Pre-monsoon	Monsoon	.0633*	0.01	0.00	0.04	0.09
		Post monsoon	0.00	0.01	0.84	-0.02	0.03
	Monsoon	Pre-monsoon	-.0633*	0.01	0.00	-0.09	-0.04

		Post monsoon	-.0606*	0.01	0.00	-0.09	-0.03
	Post monsoon	Pre-monsoon	0.00	0.01	0.84	-0.03	0.02
		Monsoon	.0606*	0.01	0.00	0.03	0.09
SMC (%)	Pre-monsoon	Monsoon	-3.5494*	0.41	0.00	-4.37	-2.73
		Post monsoon	.8767*	0.41	0.04	0.05	1.70
	Monsoon	Pre-monsoon	3.5494*	0.41	0.00	2.73	4.37
		Post monsoon	4.4261*	0.41	0.00	3.60	5.25
	Post monsoon	Pre-monsoon	-.8767*	0.41	0.04	-1.70	-0.05
		Monsoon	-4.4261*	0.41	0.00	-5.25	-3.60
WHC (%)	Pre-monsoon	Monsoon	-4.1544*	0.23	0.00	-4.63	-3.68
		Post monsoon	-4.8806*	0.23	0.00	-5.36	-4.41
	Monsoon	Pre-monsoon	4.1544*	0.23	0.00	3.68	4.63
		Post monsoon	-.7261*	0.23	0.00	-1.20	-0.25
	Post monsoon	Pre-monsoon	4.8806*	0.23	0.00	4.41	5.36
		Monsoon	.7261*	0.23	0.00	0.25	1.20

BD (g/cm^3)	Pre-monsoon	Monsoon	-.1006*	0.02	0.00	-0.13	-0.07
		Post monsoon	-.0356*	0.02	0.04	-0.07	0.00
	Monsoon	Pre-monsoon	.1006*	0.02	0.00	0.07	0.13
		Post monsoon	.0650*	0.02	0.00	0.03	0.10
	Post monsoon	Pre-monsoon	.0356*	0.02	0.04	0.00	0.07
		Monsoon	-.0650*	0.02	0.00	-0.10	-0.03
SOC (%)	Pre-monsoon	Monsoon	.4083*	0.07	0.00	0.26	0.55
		Post monsoon	.3167*	0.07	0.00	0.17	0.46
	Monsoon	Pre-monsoon	-.4083*	0.07	0.00	-0.55	-0.26
		Post monsoon	-0.09	0.07	0.21	-0.24	0.05
	Post monsoon	Pre-monsoon	-.3167*	0.07	0.00	-0.46	-0.17
		Monsoon	0.09	0.07	0.21	-0.05	0.24
Avail. N (kg/ha)	Pre-monsoon	Monsoon	-213.8689*	12.85	0.00	-239.93	-187.81
		Post monsoon	-19.16	12.85	0.14	-45.22	6.90
	Monsoon	Pre-monsoon	213.8689*	12.85	0.00	187.81	239.93

		Post monsoon	194.7111*	12.85	0.00	168.65	220.77
	Post monsoon	Pre-monsoon	19.16	12.85	0.14	-6.90	45.22
		Monsoon	-194.7111*	12.85	0.00	-220.77	-168.65
Avail. P (kg/ha)	Pre-monsoon	Monsoon	-8.6533*	0.49	0.00	-9.64	-7.66
		Post monsoon	-4.0983*	0.49	0.00	-5.09	-3.11
	Monsoon	Pre-monsoon	8.6533*	0.49	0.00	7.66	9.64
		Post monsoon	4.5550*	0.49	0.00	3.57	5.54
	Post monsoon	Pre-monsoon	4.0983*	0.49	0.00	3.11	5.09
		Monsoon	-4.5550*	0.49	0.00	-5.54	-3.57
Avail. K (kg/ha)	Pre-monsoon	Monsoon	-34.3790*	1.29	0.00	-36.99	-31.77
		Post monsoon	-17.9867*	1.29	0.00	-20.59	-15.38
	Monsoon	Pre-monsoon	34.3790*	1.29	0.00	31.77	36.99
		Post monsoon	16.3923*	1.29	0.00	13.78	19.00
	Post monsoon	Pre-monsoon	17.9867*	1.29	0.00	15.38	20.59
		Monsoon	-16.3923*	1.29	0.00	-19.00	-13.78

Exch. Na (cmol(p+)/kg)	Pre-monsoon	Monsoon	-.3272*	0.01	0.00	-0.35	-0.31
		Post monsoon	-.3389*	0.01	0.00	-0.36	-0.32
	Monsoon	Pre-monsoon	.3272*	0.01	0.00	0.31	0.35
		Post monsoon	-0.01	0.01	0.22	-0.03	0.01
	Post monsoon	Pre-monsoon	.3389*	0.01	0.00	0.32	0.36
		Monsoon	0.01	0.01	0.22	-0.01	0.03
Exch. Ca (cmol(p+)/kg)	Pre-monsoon	Monsoon	.0989*	0.03	0.00	0.04	0.16
		Post monsoon	.0878*	0.03	0.00	0.03	0.15
	Monsoon	Pre-monsoon	-.0989*	0.03	0.00	-0.16	-0.04
		Post monsoon	-0.01	0.03	0.70	-0.07	0.05
	Post monsoon	Pre-monsoon	-.0878*	0.03	0.00	-0.15	-0.03
		Monsoon	0.01	0.03	0.70	-0.05	0.07
Exch. Mg (cmol(p+)/kg)	Pre-monsoon	Monsoon	.0600*	0.02	0.00	0.03	0.09
		Post monsoon	-0.01	0.02	0.60	-0.04	0.03
	Monsoon	Pre-monsoon	-.0600*	0.02	0.00	-0.09	-0.03

	Post monsoon	-.0689*	0.02	0.00	-0.10	-0.03
Post monsoon	Pre-monsoon	0.01	0.02	0.60	-0.03	0.04
	Monsoon	.0689*	0.02	0.00	0.03	0.10

The error term is Mean Square (Error) = .003.

*. The mean difference is significant at the .05 level.

PHOTOPLATES

Plate 1: Jhum field of site Khuanggin (KG)

Plate 2: Jhum fields of site Khawkawn (KK)

Plate 3: Jhum fields of site Enpum (EP)

Plate 4: Jhum field of site NE Khawdungsei (NE)

Plate 5: Jhum field of site D. Hengkot (HK)

Plate 6: Jhum field of site Kawlbem (KB)

Plate 7: Burning of branches and twigs at site NE Khawdungsei

Plate 8: Burnt field of Enpum (EP)

Plate 9: Making hut for resting and storing at Khuanggin (KG)

Plate 10: Crops in jhum fields of D. Hengkot (HK)

Plate 11: Maize in jhum fields of Kawlbem (KB)

Plate 12: Rice cultivation in jhum fields of Enpum (EP)

Plate 13: Harvested crops from jhum field of Kawlbem (KB)

Plate 14: Harvested cucumber stored at resting hut from Enpum (EP)

Plate 15: Harvested cucumber ready for transport of D. Hengkot (HK)

Plate 16: Sun drying of harvested maize seeds of Kawlbem (KB)

Palte 17: Pumpkin stored for next season of Khuanggin (KG)

Plate 18: Transporting harvested crops manually at Enpum (EP)

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BSc	Environmental Science	St. Edmund's College	NEHU	2011	I	62.62
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ACHEIVEMENTS

1. Qualified National Eligibility Test (NET) for Assistant Professor held on 05-11-2017 with UGC Ref. No.: 44592/(ST)(NET-NOV 2017) in Environmental Sciences.
2. Qualified Junior Research Fellowship (JRF) in Environmental Sciences held on 08-07-2018 with UGC Ref. No.: 3804/(NET-JULY 2018)

SEMINAR/CONFERENCES ATTENDED AND PAPER PRESENTED

1. Presented poster "Ecological Analysis of Jhum Fields Along Altitudinal Gradient of Northeast India", at the International Conference on 'Climate Change and Natural Resource Management for Sustainable Development (ICNS -2024)' by School of Earth Sciences & Natural Resources Management, Mizoram University during 13-15th March, 2024.
2. Presented paper "Soil Physicochemical Properties of Current Jhum Fields Along an Altitudinal Gradient in Champhai District, Mizoram" at the International Conference on Current Trends in Biological Sciences by School of Life Sciences, Mizoram University during 18-20th March, 2024.
3. Presented poster "Seasonal Variation in Soil Quality in Jhum Fields of Churachandpur Manipur, at 'National Conference on Sustainable Solutions: Navigating Climate Change and Natural Resources', by Department of Environmental Science, Schol of Earth Sciences & Natural Resources Management (SES & NRM), Mizoram University during 19-20th June, 2024.

PUBLICATIONS

1. **L K Thang Ngaihte**, Elizabeth Nemhoihkim, O.P. Tripathi & B.P. Mishra (2024). Impact of Altitude on Soil Quality in Current Jhum Fields of Churachandpur, Manipur. *Eco. Env. & Cons. 30 (August Suppl. Issue)*, S200-S213. http://doi.org/10.53550/EEC.2024.v30i05s.032
2. **L K Thang Ngaihte**, Elizabeth Nemhoihkim, O.P. Tripathi & B.P. Mishra (2024). Seasonal Variations in Soil Properties Across Altitudinal Gradient of Current Jhum Fields in Champhai District, Mizoram. *Indian Journal of Natural Sciences*, Vol. *15*(87)/DEC/2024, 83025-83035.
3. Elizabeth Nemoihkim, Enmuanliana, **L K Thang Ngaihte** & B.P. Mishra (2024). Impact of anthropogenic disturbance on diversity and distribution of tree species in a tropical semievergreen forest of Aizawl, Mizoram, India. *Eco. Env. & Cons. 30 (August Suppl. Issue)*, S478-S486. http://doi.org/10.53550/EEC.2024.v30i05s.073

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DEPARTMENT	:	ENVIRONMENTAL SCIENCE
TITLE OF THESIS	:	ECOLOGICAL ANALYSIS OF JHUM FIELDS ALONG AN EDAPHO-CLIMATIC GRADIENT OF NORTHEAST INDIA
DATE OF ADMISSION	:	30/07/2019

APPROVAL OF RESEARCH PROPOSAL:

1. DRC	:	18.03.2020
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ABSTRACT

ECOLOGICAL ANALYSIS OF JHUM FIELDS ALONG AN EDAPHO-CLIMATIC GRADIENT OF NORTHEAST INDIA

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DEPARTMENT OF ENVIRONMENTAL SCIENCE,

SCHOOL OF EARTH SCIENCES & NATURAL RESOURCES MANAGEMENT

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ECOLOGICAL ANALYSIS OF JHUM FIELDS ALONG AN EDAPHO-CLIMATIC GRADIENT OF NORTHEAST INDIA

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In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Environmental Science of Mizoram University, Aizawl

ABSTRACT

This comprehensive study has provided valuable insights into the comparative analysis of jhum cultivation practices and their effects on crop composition, soil characteristics, crop production, and economic viability in Manipur and Mizoram, India. The present research selected Churachandpur and Champhai districts as the primary loci of investigation due to the prevalence of jhum cultivation practices among the local populace within these regions. From the designated study sites, three distinct sampling locations were identified based on their altitudinal gradients, encompassing elevations below 500 meters above mean sea level (AMSL), between 500-1000 AMSL, and exceeding 1000 AMSL. The specific sampling sites chosen from Churachandpur district include Khuanggin (KG), Enpum (EP), and D. Hengkot (HK), while the selected sites from Champhai district are Khawkawn (KK), NE Khawdungsei (NE), and Kawlbem (KB).

The objectives of this study are to carry out a detailed comparative study of jhum practice adopted in the Churachandpur district of Manipur state and the Champhai district of Mizoram State. Thus, the specific objectives of this study are as follows:

1. To document the crop composition in selected jhum fields along an agro-climatic gradient.
2. To compare the soil characteristics of the study sites.
3. To quantify the production of selected crops at the study sites.
4. To assess the economic viability of the selected jhum fields.
5. To recommend suitable management practices for sustainable agro-practices.

Soil samples were collected in replicates from each of the designated sampling sites during the pre-monsoon (March – June), monsoon (July – October), and post-monsoon (November – February) seasons, and the physical and chemical properties of the collected soil samples were analysed at the ICAR-RC facility located in Lamphelpat, Imphal, following well-established laboratory procedures outlined in Anderson & Ingram (1993), Bernard (1963), Walkley & Black (1934), Subbiah & Asija (1956), Bray & Kurtz (1954), and Hanway & Heidal (1952).

Crop growth and yield were also analysed from each sampling site, with maize and cucumber selected as the focus crops for this analysis as they were present in all the sampling sites; for the maize plants, the number of leaves, Leaf Area Index (LAI), number of cobs per plant, weight of the corn biomass, and harvest index, were recorded and analysed, while for the cucumber plants, the vine length, LAI, number of leaves per plant, number of fruits per plant, weight of the fruits, yield per hectare, total biomass, and harvest index were recorded and analysed. Thus, providing a comprehensive assessment of the agricultural productivity across the sampling sites and seasons.

The jhum fields were also evaluated for their economic viability using Cost-Benefit Analysis. The costs associated with jhum cultivation, including land preparation, crop establishment, maintenance, and harvesting, were carefully documented and analysed. Similarly, the benefits derived from the jhum systems, such as the monetary value of the harvested crops, were quantified. By comparing the total costs and benefits, the economic efficiency and profitability of the jhum farming practices were assessed. This cost-benefit analysis provided crucial insights into the economic sustainability of the traditional jhum cultivation systems practiced within the study region.

The following results were obtained from the in-depth analysis:

The mode of operation in the jhum fields was found to be remarkably consistent across the study sites in both districts. The cultivation process followed a similar pattern, with minor variations in field size (ranging from 1 to 1.4 ha), seed sowing schedules (mostly in March), and labour requirements (two to three people per field). This highlights the shared cultural and ecological context of the region and the common challenges faced by jhum cultivators, such as soil erosion, declining soil fertility, and the need for sustainable land management practices.

Crop composition analysis revealed similarities and variations across the study sites. Cucurbitaceae and Poaceae were the most common families, with cucumber and maize consistently growing at all sites. Other common crops include beans, pumpkins, and taros. The diversity of crops grown in the jhum fields, with an average of 8 to 13 different crops per site, highlights the importance of the jhum system in maintaining agro-biodiversity and supporting local food security.

The sand content in Churachandpur ranges from 63.17% to 87.75%. It was highest at site HK (87.75 ± 0.03%) during the monsoon season in the subsurface layer, whereas the lowest was observed at site HK (63.17 ± 0.03%) during the post-monsoon season in the surface layer. In Champhai, the sand content ranges from 63.56% to 90.86%. It was highest at site KB (90.86 ± 0.14%) during the monsoon season in the subsurface layer, while the lowest was observed at site KK (63.56 ± 0.04%) during the post-monsoon season in the surface layer.

The silt content in Churachandpur ranges from 2.33% to 31.32%. It was highest at site HK (31.32 ± 0.29%) during the post-monsoon season in the surface layer, whereas the lowest was observed at site EP (2.33 ± 0.02%) during the monsoon season in the subsurface layer. In Champhai, the silt content ranges from 2.10% to 25.94%. It was highest at site KK (25.94 ± 0.12%) during the post-monsoon season in the surface layer, while the lowest was observed at site KB (2.10 ± 0.07%) during the monsoon season in the subsurface layer.

The clay content in Churachandpur ranges from 2.28% to 19.82%. It was highest at site KG (19.82 ± 0.06%) during the post-monsoon season in the surface layer, whereas the lowest was observed at site EP (2.28 ± 0.08%) during the pre-monsoon season in the surface layer. In Champhai, the clay content ranges from 1.73% to 14.19%. It was highest at site KK (14.19 ± 0.19%) during the monsoon season in the subsurface layer, while the lowest was observed at site KB (1.73 ± 0.03%) during the pre-monsoon season in the subsurface layer.

The soil texture in Churachandpur was predominantly loamy sand to sandy loam, whereas the soil texture in Champhai was predominantly loamy sand to sandy loam, similar to that in Churachandpur, indicating comparable water retention and drainage characteristics across both districts.

The SMC in Churachandpur ranges from 16.45% to 25.40%. It was highest at site HK (25.40 ± 0.37%) during the monsoon season in the subsurface layer, whereas the lowest was observed at site KG (16.45 ± 0.15%) during the pre-monsoon season in the subsurface layer. In Champhai, the SMC ranges from 15.15% to 28.89%. It was highest at site NE (28.89 ± 0.78%) during the monsoon season in the surface layer, while the lowest was observed at site KK (15.15 ± 0.83%) during the pre-monsoon season in the subsurface layer.

The WHC in Churachandpur ranges from 32.33% to 43.58%. It was highest at site HK (43.58 ± 0.17%) during the post-monsoon season in the surface layer, whereas the lowest was observed at site EP (32.33 ± 0.10%) during the pre-monsoon season in the subsurface layer. In Champhai, the WHC ranges from 30.28% to 44.71%. It was highest at site KB (44.71 ± 0.75%) during the monsoon season in the surface layer, while the lowest was observed at site KK (30.28 ± 0.03%) during the pre-monsoon season in the subsurface layer.

The BD in Churachandpur ranges from 0.93 to 1.33 g/cm^3. It was highest at site EP (1.33 ± 0.01 g/cm^3) during the post-monsoon season in the subsurface layer, whereas the lowest was observed at site HK (0.93 ± 0.01 g/cm^3) during the pre-monsoon season in the surface layer. In Champhai, the BD ranges from 0.89 to 1.45 g/cm^3. It was highest at site KK (1.45 ± 0.02 g/cm^3) during the monsoon season in the subsurface layer, while the lowest was observed at site KB (0.89 ± 0.01 g/cm^3) during the pre-monsoon season in the surface layer.

The soil pH in Churachandpur ranges from 5.55 to 6.48. It was highest at site KG (6.48 ± 0.03) during the pre-monsoon season in the surface layer, whereas the lowest was observed at site KG (5.55 ± 0.03) during the monsoon season in the subsurface layer. In Champhai, the soil pH ranges from 5.48 to 6.21. It was highest at site NE (6.21 ± 0.02) during the pre-monsoon season in the surface layer, while the lowest was observed at site NE (5.48 ± 0.03) during the monsoon season in the subsurface layer.

The EC in Churachandpur ranges from 0.11 to 0.26 dSm^{-1}. It was highest at site KG (0.26 ± 0.01 dSm^{-1}) during the post-monsoon season in the surface layer, whereas the lowest was observed at site EP (0.11 ± 0.01 dSm^{-1}) during the monsoon season in the subsurface layer. In Champhai, the EC ranges from 0.11 to 0.21 dSm^{-1}. It was highest at site KB (0.21 ± 0.02 dSm^{-1}) during the pre-monsoon season in the subsurface layer, while the lowest was observed at site KK (0.11 ± 0.02 dSm^{-1}) during the monsoon season in the subsurface layer.

The SOC in Churachandpur ranges from 1.50% to 3.53%. The highest SOC was observed at site HK (3.53 ± 0.17%) during the post-monsoon season in the subsurface layer, while the lowest was recorded at site EP (1.50 ± 0.10%) during the monsoon season in the subsurface layer. In Champhai, the SOC ranges from 0.76% to 2.92%. The highest SOC was found at site KB (2.92 ± 0.04%) during the pre-monsoon season in the surface layer, whereas the lowest was noted at site KK (0.76 ± 0.10%) during the monsoon season in the subsurface layer.

The Avail. N in Churachandpur ranges from 219.52 to 616.75 kg/ha. The highest Avail. N was observed at site HK (616.75 ± 10.45 kg/ha) during the post-monsoon season in the surface layer, while the lowest was recorded at site HK (219.52 ± 18.11 kg/ha) during the pre-monsoon season in the subsurface layer. In Champhai, the Avail. N ranges from 135.89 to 669.01 kg/ha. The highest Avail. N was found at site KB (669.01 ± 20.91 kg/ha) during the monsoon season in the surface layer, whereas the lowest was noted at site KK (135.89 ± 10.45 kg/ha) during the pre-monsoon season in the subsurface layer.

The Avail. P in Churachandpur ranges from 19.44 to 38.10 kg/ha. The highest Avail. P was observed at site HK (38.10 ± 2.86 kg/ha) during the monsoon season in the surface layer, while the lowest was recorded at site EP (19.44 ± 1.26 kg/ha) during the pre-monsoon season in the subsurface layer. In Champhai, the Avail. P ranges from 18.10 to 35.75 kg/ha. The highest Avail. P was found at site KB (35.75 ± 1.16 kg/ha) during the monsoon season in the surface layer, whereas the lowest was noted at site NE (18.10 ± 0.48 kg/ha) during the pre-monsoon season in the subsurface layer.

The Avail. K in Churachandpur ranges from 153.14 to 263.68 kg/ha. The highest value was observed at site HK (263.68 ± 1.76 kg/ha) during the monsoon season in the surface layer, while the lowest was recorded at site KG (153.14 ± 1.10 kg/ha) during the post-monsoon season in the subsurface layer. In Champhai, the Avail. K ranges from 138.28 to 248.14 kg/ha. The highest value was found at site NE (248.14 ± 3.39 kg/ha) during the monsoon season in the surface layer, whereas the lowest was noted at site KK (138.28 ± 1.16 kg/ha) during the pre-monsoon season in the subsurface layer.

The Exch. Na in Churachandpur ranges from 1.33 to 1.79 cmol(p^+)/kg. The highest value was observed at site EP (1.79 ± 0.04 cmol(p^+)/kg) during the post-monsoon season in the subsurface layer, while the lowest was recorded at site KG (1.33 ± 0.01 cmol(p^+)/kg) during the pre-monsoon season in the surface layer. In Champhai, the Exch. Na ranges from 1.32 to 1.75 cmol(p+)/kg. The highest value was found at site KK (1.75 ± 0.01 cmol(p^+)/kg) during the monsoon season in the subsurface layer, whereas the lowest was noted at site NE (1.32 ± 0.02 cmol(p^+)/kg) during the pre-monsoon season in the surface layer.

The Exch. Ca in Churachandpur ranges from 0.53 to 1.91 cmol(p^+)/kg. The highest value was observed at site HK (1.91 ± 0.07 cmol(p^+)/kg) during the pre-monsoon season in the surface layer, while the lowest was recorded at site EP (0.53 ± 0.13 cmol(p^+)/kg) during the pre-monsoon season in the subsurface layer. In Champhai, the Exch. Ca ranges from 0.61 to 1.97 cmol(p^+)/kg. The highest value was found at site KB (1.97 ± 0.03 cmol(p^+)/kg) during the pre-monsoon season in the surface layer, whereas the lowest was noted at site KK (0.61 ± 0.09 cmol(p^+)/kg) during the pre-monsoon season in the subsurface layer.

The Exch. Mg in Churachandpur ranges from 0.95 to 1.66 cmol(p+)/kg. The highest value was observed at site EP (1.66 ± 0.04 cmol(p+)/kg) during the post-monsoon season in the subsurface (15–30 cm) layer, while the lowest was recorded at site HK (0.95 ± 0.04 cmol(p+)/kg) during the post-monsoon season in the surface (0–15 cm) layer. In Champhai, the Exch. Mg ranges from 0.95 to 1.68 cmol(p+)/kg. The highest value was found at site NE (1.68 ± 0.03 cmol(p+)/kg) during the post-monsoon season in the surface layer, whereas the lowest was noted at site KK (0.95 ± 0.04 cmol(p+)/kg) during the post-monsoon season in the surface layer.

Both maize and cucumber cultivation appear to be profitable in both districts, with benefit-cost ratios consistently above two for maize and above three for cucumber. There was slight variation in input costs and outputs between sites, which may be due to local conditions or farming practices. Cucumber cultivation shows higher profitability than maize in both districts, with higher benefit-cost ratios and absolute profit figures. The profitability of both crops appeared to be relatively consistent across the two districts, suggesting that both Churachandpur and Champhai were suitable for maize and cucumber cultivation.