# STUDIES ON WOOD CHARCOAL PRODUCTION, UTILIZATION AND ITS ENVIRONMENTAL IMPACT IN MIZORAM

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# STUDIES ON WOOD CHARCOAL PRODUCTION, UTILIZATION AND ITS ENVIRONMENTAL IMPACT IN MIZORAM

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Submitted
in partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl

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**DECLARATION**

I Mr. H. T. Lalmuankima, 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/Instituted.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Forestry.

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## CERTIFICATE

This is to certify that the thesis entitled "**Studies on wood charcoal production, utilization and its environmental impact in Mizoram"** submitted by **Mr. H. T. Lalmuankima** (Ph.D. Regn. No. **MZU/Ph.D./458 of 15.05.2012**) in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in the Department of Forestry, Mizoram University, Aizawl embodies the record of original investigations carried out by him under our supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of degree of Doctor of Philosophy (Ph.D.). The thesis or part of these has not been submitted by him for any degree to this or any other University.

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| | |
|---|---|
| ASTM | American Society for Testing Materials |
| ANOVA | Analysis of Variance |
| BTU | British Thermal Unit |
| CEC | Cation Exchange Capacity |
| cmol/kg | Centimole per kilogram |
| CRD | Completely Randomized Design |
| CHAPOSA | Charcoal Potential in Southern Africa |
| DAO | District Agriculture Officer |
| DAT | Day after transplant |
| dS/m | Decisiemens per metre |
| EC | Electrical Conductivity |
| E&FDSH | Environment & Forests Department Statistical Handbook |
| ESMAP | Energy Sector Management Assistance Programme |
| FAO | Food and Agriculture Organization of the United Nations |
| GC | Gas Chromatography |
| GDP | Gross Domestic Product |
| HAMP | Department of Horticulture, Aromatic and Medicinal Plants, Mizoram University, Aizawl |
| IAP | Indoor Air Pollution |
| IBEF | India Brand Equity Foundation |
| ICRAF | International Council for Research in Agroforestry |
| IEA | International Energy Agency |
| IIFM | Indian Institute of Forest Management, Bhopal |
| IIM | Indian Institutes of Management |
| INBAR | International Network for Bamboo and Rattan |
| IPCC | Intergovernmental Panel on Climate Change |
| LPG | Liquefied Petroleum Gas |
| LPK | Long Platform Kipper |
| MIRSAC | Mizoram Remote Sensing Application Centre |
| MJ/kg | Megajoule per kilogram |

| | |
|---|---|
| MPa | Megapascal |
| NMVOCs | Non Methane Volatile Organic Compounds |
| NTFPs | Non-timber Forest Products |
| OPSTAT | Operational Statistics |
| PAC | Percentage Ash Content |
| PCK | Partial-combustion Kiln |
| PFC | Percentage Fix Carbon |
| PVM | Percentage Volatile Matter |
| RWEDP | Regional Wood Energy Development Programme |
| SEI | Stockholm Environment Institute |
| SEM | Scanning Electron Microscopy |
| SSA | Sub Saharan Africa |
| TAPPI | Technical Association of the Pulp and Paper Industry |
| UNDP | United Nations Development Program |
| UNFPA | United Nations Population Fund |
| USDA | United States Department of Agriculture |
| WHC | Water Holding Capacity |

## PHOTO PLATES

## Chapter 1

## INTRODUCTION

Charcoal is a lightweight carbon and ash residue hydrocarbon produced by removing water and other volatile constituents from biomass resources. Charcoal is the general term for a range of carbonized materials with varying combustion and dark properties (Amanor *et al.,* 2002). Charcoal is produced by a process called carbonization, a process by which solid residues with increasing content of carbon are formed from organic material usually by pyrolysis in an inert atmosphere. In the course of pyrolysis, biomass undergoes a sequence of changes and normally produces a black carbonaceous solid called charcoal, along with a mixture of gases and water. Normally, in carbonization, charcoal production is maximized in a course of slow heating rates at low temperatures during pyrolysis.

Wood charcoal is mostly pure carbon, made by heating wood above 400ºC in a low oxygen situation. The process, can take days and burns off volatile compounds such as water, methane, hydrogen and tar (http://ukrfuel.com/news-how-to-make-wood-charcoal-19.html). The material left behind is a black, porous charcoal that retains the original form of the wood but has just one fifth the weight, one half the volumes, and about one third of the original energy content (Amanor *et al.*, 2002). During the whole process the low temperature is maintained to prevent most of the wood from igniting during production.

The factors affecting wood carbonization are - the nature of wood, wood chemical composition, wood structure and physical properties such as density, permeability, thermal conductivity, size and shape and various external conditions such as temperature, heating rate and pressure (Kataki, 2005). Wood chemical components can be distinctly divided into two groups. The main group is the macromolecular cell wall components viz., cellulose, polyoses (hemicellulose) and lignin which are present in all woods and the minor low-molecular-weight components *viz*. extractives and mineral substances. The proportion and chemical composition of lignin and polyoses differ in softwoods and hardwoods, while cellulose is a uniform component of all woods. Wood properties can differ, not only from species to species but also within a given species and from point to point in the same tree. Despite of their differences, wood from a variety of sources exhibit many similarities. The essential properties of wood as a raw material for charcoal production such as ash content, density, cellulose content, fixed carbon content, etc. vary with the species; however, no such conclusion has been drawn regarding the effect of extractives on the yield and quality of charcoal (Saikia *et al.*, 2007).

Charcoal is an age old refined form of woodfuel and has been known from even before the dawn of recorded history. It is an important energy source for domestic cooking and heating purposes. It has wide range of industrial and processing applications such as manufacturing of activated carbon, calcium carbide, carbon disulfide, silicon carbide, sodium cyanide, reduction of iron-ore in the steel industry, refining of metals (eg. copper, bronze, silicon, aluminum and electromanganese) black smiths, cloth ironing, heavy-clay soil conditioner, planting medium etc. Despite its comparatively higher price than other woodfuels, wood charcoal is able to compete with fossil carbons because of its relative purity (low ash content) and high reactivity. The major reasons attributed to charcoal usage are its affordability, gathered/collected free in some cases and the higher taste and preference of consumers for it. It is also used as a backup fuel. In the commercial and industrial sector, large number of (prepared) –food vendors, such as restaurants and bakeries use wood charcoal; distillery factories and blacksmiths also depend on it. Institutions such as hospitals, schools and prisons are among the highest consumers of wood fuel/charcoal in many developing countries (Bensel and Remedio, 1993). Nevertheless wood charcoal remains the dominating source of fuel energy in most of the developing countries. Its advantages when used as a domestic fuel are that it produces less smoke while burning, requires little or no preparation before actual use, has a higher energy content per unit mass, it can be easily transported and stored, longer shelf-life, do not blackened utensils and can be reused when left over after cooking. Thus, comparing to other biomass fuels charcoal is cleaner, easier and less smoky and smelly. In those developing countries with abundant forest resources the export of charcoal can be a profitable industry. Charcoal can be made from any organic material, like wood, straw, coconut shells, rice husks, bones, etc. Amongst wood, generally the hardwood species are preferred for charcoal making e.g. Mangroves, Oaks, *Acacia*, *Prosopis* (Bhattarai, 1998). It can be used in smaller quantities with cheap burning devices for domestic application. According to Ellegard and Nordstrom (2003), due to its low cost compared to other fuels like kerosene and liquefied petroleum gas (LPG) as well as other factors the demand for charcoal is expected to continue rising dramatically in the coming decades, despite best efforts by modern energy advocates. Moreover, charcoal has been an important domestic product for many years and, regardless of how it is produced, it has wide market acceptance for its great uses. This market has stimulated interest in the manufacture of charcoal globally. The increasing demand of charcoal as recreational fuel, and production will continue to expand as this use increases (Bhattarai, 1998).

According to FAO (2008), sixty percent of all wood taken from the world's forests is believed to be burnt as fuel - either directly or by first converting it into charcoal. The proportion of fuelwood used to make charcoal can only be estimated. But it is probably around 25 percent or about 400 million cubic metres per year throughout the world. While there are numerous efforts to mitigate destruction of forest resources through technological innovation, there exists a large gap in research on the true impacts sustained by the people and their environments.

The reduction in forest cover has left the charcoal producers of the state available nearby and this has in turn affected both quality and quantity of charcoal. In addition, economically important tree species are also used up in charcoal production. Therefore, extensive farming of selected tree species in available wastelands could be a viable alternative to bridge the gap between demand and supply with little choice about the selection of tree species for charcoal making. Survey has revealed that rural populations of Mizoram have strong preferences for certain tree species for charcoal production. But as resources become scarce and preferred species are not sufficiently available, presently the charcoal producers are using all kinds of tree species for charcoal production. In this regard, no systematic work has been done so far to characterize these tree species from the charcoal production point of view. Ravindranath *et al.,* (1991) opined that before undertaking any programme of biomass production, local tree species diversity, traditional preference of tree species for various purposes and information regarding the performance of different species in that area should be taken into consideration.

According to Ogunsanwo (2001a), one of the promising solutions to the problems of unutilized agricultural residues and wood waste is the application of charcoal production technology by knowing which wood species has the highest heating value and low ash content. Bailey and Blankenhorn (1984), Hines and Eckman (1993) described the desirable criteria for quality wood charcoal as having low moisture content, relatively easy to cut, easy to handle, easy to ignite and burn with high calorific value/heating value, producing very little or no smoke without toxic fumes and neither spits nor sparks. They retain grain of the wood; it has jet black colour with shining luster; it is sonorous with metallic ring and does not soil the finger (Ijagbemi *et al.,* 2014). These criteria are found in many tropical wood species and other woody species.

Charcoal-making practices are empirical in nature with a built-in traditional wisdom inherited from one's ancestors. Clear scientific study of the whole process with the interventions for controlling the influencing parameters is lacking. Production and trade of charcoal often serves as an additional income earning opportunity, it also helps people to convert the off-season into a cash earning opportunity. Therefore, most of the charcoal that is brought to local markets by traditional producers, usually in small or large amounts as, is a product of the surrounding and distant public or community forests.

Therefore, charcoal trade offers income generation opportunities for many people in both urban and rural areas through small scale retail businesses mostly run by women who sell it in the urban areas as in the case in Mizoram. The practice is prevalent in areas where the local demand for charcoal is limited and the market is small, (e.g. only for specific uses *viz.* smithies, ironing, etc.), consequently the main markets are usually in the urban and sub-urban areas irrespective to the level of income. In many countries, the rural people and charcoal producers have ample supply of wood fuel as their energy resources and the actual demand for charcoal is found in the urban and sub-urban areas. This often means that the charcoal is produced far from the demand and must be transported to the user, mostly the city and town areas, since the urban environments which is ever growing population depends on charcoal as secondary source of energy for cooking and heating, especially on commercial sectors. Ribot (1993, 1998) conducted a commodity chain analysis on charcoal industry and found that despite substantial regulations, a majority of benefits, both economic and socio-political, accrue to merchants and wholesalers involved in the trade compared to producers. Rural producers, who often make up the largest portion of the employed force, generally lack the capital to increase their own earnings, or even maintain just above subsistence income (Post and Snel, 2003). Even in countries where more progressive policies exist with regards to the charcoal industry, producers are still often disadvantaged with respect to income generation and labour support (Schure *et al.*, 2013). This is particularly concerning in most countries where charcoal is left out of the formal economy (Cuvilas *et al.*, 2010).

Intertwined in charcoal production and its use are global environmental effects. Because most of the charcoal feedstock is not from plantation wood, the unsustainable and unscientific harvesting of biomass results in net carbon dioxide emissions. Nevertheless, charcoal production may also have negative impact on environment and soil fertility of the charcoal production sites and its surrounding area.

Fontodji *et al.*, (2009) revealed that the soil physical, chemical and microbial properties were changed in charcoal production areas. The organic matter was destroyed; it is higher at the unburnt plot level than inside the kiln. The soil pH increased at the kiln level by the provision of rich ash bases during the carbonization. Fire increased the permeability at the kiln level by raising the bulk density and the total porosity of soil. Glaser *et al.,* (2002) concluded that charcoal residues and charred biomass left on the kiln sites has been also found to serve to ameliorate and, improve the fertility of tropical soils by direct nutrient addition and retention. According to Oguntunde *et al.,* (2004), available phosphorus, exchangeable bases, total nitrogen, organic carbon and base saturation was higher in soils of charcoal production sites than the adjacent lands. A study conducted also showed that bulk density on charcoal-site soils reduced by 9% compared to adjacent field soils. Oguntunde *et al.,* (2004) observed that the grain and biomass yield of maize and also increased by 91% and 44%, respectively, on charcoal production sites soils as compared to adjacent farmland soil. They however, opined for the need of further research to ascertain the long-term effects of charcoal production on the soil environment and the fertility of tropical soils.

The most significant impacts occurring during charcoal production and usage are emissions into the working environment and air. Besides the production of charcoal, pyrolysis of biomass also produces incomplete combustibles, such as methane and other harmful gases, which may have a higher global warming impact than carbon dioxide. In fact, the main global warming impact of the charcoal cycle may result from the biomass pyrolysis and not the end-use of charcoal burning. The pollutants emitted included green-house-gases, tars, NMVOCs (Non Methane Volatile Organic Compounds) and particulate matter. On the global and regional scale they contribute to the global warming, while on the local scale they may impose health risk for the workers and people living in the vicinity of production site (FAO, 2008). Abdullahi (2012) reported in his survey that most interviewed groups complained about some type of ailments attributable to charcoal production or use. It should be noted, however, that all of the ailments mentioned are very mild and do not result in any serious or chronic disease. Incomplete burning of charcoal, particularly in a confined space, can lead to exposure to carbon monoxide, an odourless gas which, by combining with haemoglobin, deprives the body of oxygen and can cause death.

This process has direct linkages to negative social health outcomes. Lack of modern tools most often results in the use of human labour throughout the entire production process. Not including time spent during extraction and packaging, producers will often spend over two weeks vigilantly monitoring the kiln to ensure that the process of carbonization in the absence of oxygen, or pyrolysis, is properly conducted (Ribot, 1993). Extreme temperatures combined with volatile chemical compounds, including carbon monoxide and sulfur dioxide; create an extremely dangerous environment for any human, especially those without adequate safety protection. Producers are often known to spend the night within a few feet of a burning kiln to ensure that any gaps are quickly sealed. The United Nations Food and Agricultural Organization (FAO) released a working document highlighting the dangers associated with industrial charcoal production in the developing world and the precautionary measures that should be taken by producers (FAO, 1985). However, lack of proper knowledge, institutional capacity and financial resources prevents these safety measures from being taken in most areas that produce charcoal for residential use, contributing to the prevalence of moderate to severe injury and illness.

Health-related impacts associated with woodfuels/charcoals have traditionally focused on effects from their consumption. Indoor air pollution (IAP) is the primary concern given the high concentrations of smoke and particulate matter released during combustion. However, little is known about the health impacts endured by charcoal producers during extraction and production phases (Subramanian, 2000). For example, it is known that pyrolysis, the process utilized for the production of charcoal, releases significant amounts of gaseous by-products, including carbon monoxide, sulfur dioxide and others (Bailis *et al.*, 2005; Pennise *et al.*, 2001) known to be deadly to humans in moderate concentrations through the use of dose-response studies (Muhammad *et al.*, 2005). Rural producers are known to work within close proximity to high temperature kilns that off-gas these highly toxic compounds, generating potential high risk for poisoning. In addition, use of primitive tools can potentially lead to moderate or severe injuries, which can prove fatal in rural areas that lack access to adequate medical care. Academic literature and government reports refer to the working conditions of charcoal producers as unsafe (Arnold *et al.*, 2006; World Bank, 2012); government officials and research papers alike mention these 'hazards' in passing.

Charcoal making through its detrimental effects on rangelands and soil fertility may leads to the reduction of wildlife and biodiversity. Perhaps a large number of soil fauna and plant species may be killed by the fire during raw material preparation and during pyrolysis. Low process efficiencies, combined with unregulated actions of many producers, cause large volumes of wood to be harvested from nearby forests (de Miranda *et al.*, 2010; Brouwer and Falcao, 2004; Hosier and Milukas, 1992). These areas are often sections of communally-owned land, but can also make up large portions of protected forests. As a result of weak, unenforced or disjointed forest policies, many countries in Sub Saharan Africa (SSA) are experiencing increased rates of deforestation from charcoal production in protected areas. Unlike the use of fuelwood for cooking and heating, which is often supplied from ground harvesting and has no major impact on environmental degradation (Brouwer and Falcao, 2004; Zulu, 2010), current methods of charcoal production require vast amounts of resources for relatively little return.

It takes seven to ten tons of raw wood to produce one ton of wood charcoal, making wood fuel collection an important driver of deforestation (INBAR, 2011). On a local scale, the effects of charcoal use are mostly related to the inefficiency of production, forestry and land degradation and the transportation distances. Because most of the energy of the fuel wood is lost in the production process, charcoal users ultimately use much more fuel wood than direct fuel wood users. Since charcoal is typically produced in sizable batches, it is rarely linked with sustainable forestry practices and is more often linked with clear cutting. At best, charcoal may be produced from plantations, but it is more likely to be produced from land cleared for agricultural purposes or smaller areas cleared specifically for charcoal production.

This issue becomes compounded when considering the low replanting rates and poor land management practices that have been identified across the region.

Lack of resources; educational, financial or otherwise, has been cited as the major reason for such trends. The link between environmental degradation and rural livelihood is quite clear in the utilization of forest resources. Lack of emphasis on rural livelihoods in national energy and resource policies lead to widespread slash and burn practices, erosion and increasing levels of deforestation due to desperate attempts by rural communities to generate income through the exploitation of forest resources. Larson and Ribot (2007) provide comprehensive evidence that forestry laws and policies across the developing world are skewed in favor of the elite. Efforts to mitigate these environmental impacts and promote social development are often concentrated in urban areas, where population densities and government resources make it relatively easy to enact these changes. Still, charcoal production in rural areas has been increasingly linked to large-scale deforestation due to clear felling and agricultural land use following production. Some previous work has been conducted, highlighting the very real threat that current methods of production have on society and the environment. Mwampamba (2007) modelled current and future deforestation rates based on survey data gathered on extraction and replenishing habits of rural charcoal producers finding that by 2028, public forest resources will be depleted if policy interventions are not put in place. In addition, further research at local or sub-national levels can provide decision makers with information regarding geographical trends in energy dynamics. An attempt to criminalize this behaviour by imposing fines, high taxes and restrictions on production levels are common and not only creates additional livelihood pressure on rural communities, but leads to a national charcoal dichotomy.

Charcoal based activities are reported in many developing and poor nations of the world. According to INBAR (2008) least 80% of the African populations continue to rely upon traditional sources of biomass fuels mainly charcoal and firewood to meet their energy needs. Charcoal is one of the most important commodities produced by the rural poor across Africa which is largely used in urban areas (Jones, 2015). It is an important and simple means of income generation and in rural areas its production can be the more important than other activities such as agriculture. Charcoal also contributes to a reliable, convenient and accessible energy for cooking at all times and at a stable cost. Most of Africa's charcoal energy use occurs in sub-Saharan Africa. In Mozambique alone, a study has shown that over $200 million of charcoal is sold in the town and cities where it is primarily used for cooking.

According to Jones (2015), the bulk of charcoal wood is clear-cut from secondary, and in some cases, from primary forests. Hence, charcoal leads to considerable deforestation, which is now one of the most pressing environmental problems faced by most African nations. Large-scale charcoal production, primarily in sub Saharan Africa, has been a growing concern due to its threat of deforestation, land degradation and climate change impacts. It is cited as the most environmentally devastating phase of this traditional energy supply chain, and despite increasing per capita income, higher electrification rates, and significant renewable energy potential, charcoal still remains the dominant source of cooking and heating energy in Sub Saharan Africa (SSA) (Arnold *et al.*, 2006; Zulu and Richardson, 2013). As a traditional fuel that has been used for hundreds of years, it serves as a lifeline for the rapidly increasing populations in the urban centers of the region, in addition to potentially significant portions of the rural population. Charcoal use in SSA is predicted to double by 2030, with over 700 million Africans relying on it as a durable, preferred, and cheap source of energy (Ishengoma and Kappel 2006). Charcoal industries in some of the top producing countries, namely Tanzania and Uganda, employ tens to hundreds of thousands of citizens, many of whom receive up to 70% of their annual income from this market (Goanue, 2009) (Zulu *et al.*, 2013).

Similarly, the situation in South Asia varies in terms of charcoal production and use. In Ahmedabad, India, it is reported that, besides the laundry units which are significant consumers of traded charcoal for ironing of clothes, the middle class people also used some briquettes made of charcoal dust for household cooking (RWEDP, 1993a). Other end-uses of charcoal were, among others, lead extraction and metal processing, coriander seed processing, roadside catering and food vending, and student hostels. Industrial applications of charcoal included manufacturing of incense sticks and extraction of calcium carbonate from limestone. These industries consumed a large amount of high grade locally traded charcoal. The average volume of charcoal supplied per annum in Ahmedabad City alone is reported to be 23,842 metric tons between 1986 to 1990. This includes the amount supplied from other States. In terms of the economic gain, it is stated that the farmers who produced charcoal got a 14% higher return compared to those who sold fuelwood.

Charcoal production industry, particularly in India is largely not organized. The industrial sectors which appear to be the major user of charcoal are silicon industries and cooking sectors. However, there are many industrial sectors which require charcoal in small quantities**.** In India 3-4 million people are believed to be involved in woodfuel trade, which makes it the largest source of employment in the energy sector (Bhattarai, 1998). Charcoal production and trade are reported in several states, such as Gujarat, Andhra Pradesh and Tamil Nadu. The wood fuel markets in many regions of India are quite exploitative. In India, a considerable quantity of charcoal is used in urban areas for applications ranging from industrial processing to domestic cooking. Unfortunately, field information on various aspects of charcoal production, distribution and consumption is almost non-existent. In order to promote development and proper technical intervention in charcoal production and positive links with social forestry and wasteland development programmes, collection of first-hand information on charcoal markets and marketing practices would be useful.

In the state of Mizoram in particular and the whole of north-east India in general, woodfuels constitute up to 80% of the total energy consumption and over 90% of the population of this north-eastern Himalayan region uses biomass as an important source of energy (Bhat and Sachan, 2004). Generally, the charcoal traders are engaged in the illicit cutting of trees from public lands which is ignored by the local-level government functionaries in the Revenue and Forest Departments (Saxena, 1997). Besides income from agriculture, production of charcoal becomes a form of insurance against crop failures, income during off season, emergency cash needs, etc. In addition, charcoal trade provides opportunities for many people in urban areas and sub-urban areas, through small scale retail businesses selling it in the markets and even at several localities.

In most of the regions, the population continues to rely upon traditional sources of biomass fuels, mainly charcoal and firewood to meet their energy needs. At the same time, charcoal is one of the most important fuel energy produced by the rural poor across Mizoram which is widely used in urban areas. Since, charcoal is a reliable, convenient and accessible energy source for cooking at all times and at a stable cost, the demand for charcoal in most of the regions continues to grow owing to the ever-increasing rural-urban migration. These trends coupled with inefficient charcoal production and consumption practices and inaccessibility by most households to other reliable and affordable commercial energy. Evaluation of fuelwood consumption rates and status of forest resources in the north-eastern Himalayan region has lead Bhat and Sachan (2004) to conclude that the estimated growing stock is unable to sustain the rate of fuel consumption in this region.

According to Census of India 2011 (INDIA, 2011), Provisional Population Totals Paper 2, Volume II about 690 families in urban areas and 275 families in rural areas of Mizoram are still totally depend on wood charcoal as domestic fuel. As per the Statistical Handbook 2011 of Environment & Forests Department Revenue returns of charcoal to the State for the last five years (**Table 1.1**) shows that there is a continuous and increasing demand of charcoal within the State.

**Table 1.1:** Status of wood charcoal production in Mizoram

| **Sl. No.** | **Year** | **Quantity in qtls.** | | **Amount in Rs.** | |
|---|---|---|---|---|---|
| | | Legal | Illegal | Legal | Illegal |
| 1. | 2006-2007 | 788 | 1935.38 | 8,472 | 30,014 |
| 2. | 2007-2008 | 2502 | NA | 24,322 | NA |
| 3. | 2008-2009 | 953.2 | 415 | 13,087 | 7,468 |
| 4. | 2009-2010 | 263.8 | 782 | 1,991 | 20,444 |
| 5. | 2010-2011 | NA | 2723 | NA | 147,153 |

*Source: Statistical Handbook, 2011, E&F Deptt, Govt of Mizoram,* (E&FDSH, 2011)

The economy of over half of the population in Mizoram is entirely based on land and Jhuming/shifting cultivation is the mainstay of the people (Economy Survey Mizoram, 2008-09). As more than 80 % of the forest land in Mizoram is owned by individual or community, the raw material is collected free of cost. Thus, charcoal business has flourished well in the state becoming a good income source among rural masses. Land tenure in many parts of Mizoram is particularly well organized. Customary land tenure are often exercise by the Village Council and by virtue of their authority, the village own lands are leased out to each families for a year for cultivation where they are allowed to produce charcoal from the felled trees, providing adequate land management practices and ultimately limited area. However, there are cases that the producers purchased some amounts of woods from their neighbouring leased land to meet their additional requirement of raw materials for charcoal. Apart from these, there are several people who commit their occupation as charcoal manufacturer and traders, supplying the materials to the sub-urban and urban areas for different end-uses and even within the rural villages for domestic cooking. Since, the chain of market is usually operated by the wholesale stockists/merchants from urban areas; the actual producers are living in a condition of virtual bonded labor. Charcoal production, its supply chain, substantial studies on species used, the supply chain and the impact on the society is therefore needs to be studied. Therefore, the major part of the study is carried out on different aspects of the charcoal continuum, i.e. household energy, livelihoods, supply chains, wood charcoal quality attributes and the environmental aspects. Though charcoal production has been practiced in the hilly states of north-east India, particularly in the state of Mizoram, since the long past, no scientific study has been made so far to identify the indigenous tree species of the region, which can produce charcoal with higher yield and of better quality. Moreover, no work has been done to assess the actual yield of charcoal and other by-products of carbonization of wood of these indigenous tree species. It is anticipated that the information gathered and especially the findings and recommendations of the study will bring about a renewed awareness of the importance of charcoal and also help in formulating efficient policies and strategies sustainable utilization of this valuable resource in the state and the region as well.

**Objectives:**

1. To study production status and utilization pattern of wood charcoal in Mizoram.
2. To assess quality of charcoal produced from different species of Mizoram.
3. To study the impact of charcoal production on Environment.

# Chapter 2

# REVIEW OF LITERATURE

Forests provide a range of products and services, directly contributing to the livelihoods of an estimated 800 million people globally, living in or near tropical forests (Chomitz *et al.,* 2007). Through the provision of timber and non-timber forest products (NTFPs) such as food, fodder, medicine, housing materials and fuel, forests contribute to livelihoods by providing access to basic materials and income generation (Shackleton *et al.,* 2011). Forest-derived incomes contribute considerably to rural livelihoods and can reduce households' vulnerability by providing a source of savings, asset building, reducing poverty levels and improving well being (Angelsen *et al.,* 2014). More than 2 billion people used fuel wood or charcoal as energy to cook and preserve food (Broadhead *et al.,* 2001). Wood energy thus helps households in attaining food security. Wood charcoal production has been an important source of off farm income for rural people and significantly contributes to employment generation through its trade in many countries. Charcoal production and trade is highly unorganized and gets less attention from the policy makers. However many researchers have attempted to investigate various aspects of charcoal production and utilization in different parts of the world. The following review briefly highlights the available literature on wood charcoal production, use, trade, quality attributes and its impact on environment.

## 2.1 Production and utilization of charcoal

Charcoal burning is probably considered the oldest chemical process known to man. Tesot (2014) established that the use of charcoal started about 30,000 years ago. Charcoal which is mankind's first source of energy refers to a range of carbonized materials constituting different levels of combustion and dark properties (Lurimuah, 2011; Tesot, 2014). It is believed that without it, bronze and iron ages simply would not have happened (Carew, 1999). According to Bard (2001), biocarbons have been manufactured by men for more than 38,000 years and are still among the most important renewable fuels in use today (Mochidzuki, 2002).

In most of the developing world, charcoal makers use traditional means or build temporary earthen kilns for each batch (FAO, 2000). Charcoal production worldwide is increasing for energy use in households and industry, but it is often regarded as an unsustainable practice and is linked to agricultural frontiers (Prado, 2000). The production (Coomes and Burt, 2001) and use of charcoal in agriculture is common in Brazil and widespread in Asia (Steiner *et al.,* 2004). The Food and Agriculture Organisation (2000) points out that, charcoal is a very important energy source for households. Seasonally, charcoal consumption has taken a particular pattern. There are some 600, 000 small-scale enterprises in commercial activities, such as chop bars, street food and grills, which depend on fuel wood or charcoal as their main source of energy (Adekunle, 2012).

IIFM (2017) reported that the charcoal markets in many regions of India are quite exploitative. In Maharashtra condition of a tribal of around 4,000–5,000 families engaged in charcoal making, mostly as laborers. Around 80 per cent of these families belong to poor Katkari tribes originating from the districts of Raigad and Thane. At present about 75 per cent of charcoal is being used by industries, and the rest is used as domestic fuel. Charcoal laborers are controlled by traders, who sell the produce to stockists in Bombay. It is estimated that the original tribal laborers get around just 10 per cent of the final value in the whole production activity. Normally, charcoal making starts around the end of November and continues until May (IIFM, 2017).

In Gujarat, charcoal continues to be used by laundry units, charcoal briquette manufacturers, lead extractors, metal processing units, coriander seed processors, incense manufacturers, food vendors and hostels in Ahmedabad city. Increased supply would certainly change the situation and benefit all types of charcoal users (IIFM, 2017). As per the same report, in Tamil Nadu too charcoal making was perceived to have contributed positively to the general economy of the state, particularly in Thanjavur district. A sizeable number of agricultural laborers, who used to migrate temporarily to work on paddy fields in order to supplement the meagre incomes they could earn in their own area, have found enough employment locally to stop migrating. In India, a considerable quantity of charcoal is produced (**Table 2.1**) and used in urban areas for applications ranging from industrial processing to domestic cooking. Unfortunately, field information on various aspects of charcoal production, distribution and consumption is almost non-existent.

**Table 2.1:** Production of charcoal at selected Indian states

| Sl. No. | State | Annual Production (Metric tons) |
|---|---|---|
| 1. | Tamil Nadu | 234000 |
| 2. | Andhra Pradesh | 208000 |
| 3. | Gujarat | 114000 |
| 4. | Rajasthan | 49200 |
| 5. | Karnataka | 30000 |
| | **Total** | **636000** |

Source: www.indiastat.com (Accessed in the year 2016)

Wood fuel is a widely used energy source of the world. In Ghana, it has been estimated that, wood fuel mainly in the form of charcoal and fuel wood make up 60 percent or more of the total natural energy consumption (Energy Commission, 2010). Coder (1973) observed that the more industrialized nations used less wood fuel and the less industrialized used more wood fuel. For example, Africa and Latin America where industrialization is low, 90% of all wood used is for fuel and in Asia, 65%, but in Europe it is 25% and 10% in N-America (Earl, 1972). In the developing countries, the proportion is even more, ranging from 80% to 98% of all energy consumed. Globally, charcoal production trends between 1965 and 2005 show increasing production levels with Africa topping the chart. Africa is closely followed by Latin America and Caribbean, while Asia tails the chart, producing less than five million tonnes in 1965 and about 5.5 million tons in 2005 (Ghilardi and Steierer, 2011). According to Ghilardi and Steierer (2011), seven out of the world's top ten countries in charcoal production are from Africa. On the other hand Brazil tops the chart country wise with 11%, while China and India each produce three percent.

Charcoal production is mostly a rurally based activity. Perhaps the relatively recent presence of charcoal production within some communities has led to non-gendered production practices (Jones *et al.*, 2016), but there is limited data to suggest whether men and women achieve comparable outcomes from engaging in charcoal production. Many charcoal-based livelihoods are thus informal, and therefore fraught with uncertainty and risk from enforcement activities, and often ignored or penalised by governments (Smith *et al.*, 2015).

According to Bhattarai (1998), charcoal is an important fuel in many RWEDP member countries, mainly for two purposes: (a) cooking of food for home consumption in urban areas, and partly for commercial purposes (e.g. restaurants and eateries), (b) traditional industrial and commercial activities of numerous types. Even in countries with apparently similar circumstances, people's preferences for charcoal seem to vary notably. Bhattarai (1998) opined that some amount of charcoal is produced and used in Southern Vietnam, mostly for domestic cooking, food vending, tea drying, and in chemical and metal industries (about 80 ton produced in Can Gao District in 1991). Charcoal production industry, especially in India is largely not organized (IIFM, 2017). Hence the authenticity of the available data might require further verification. Figure 1 indicates the production/consumption of charcoal at global, national, state, user industries and households level. Figure1 explain that the charcoal production is mainly concentrated in African region followed by Latin America/ Caribbean and Asia-Pacific.

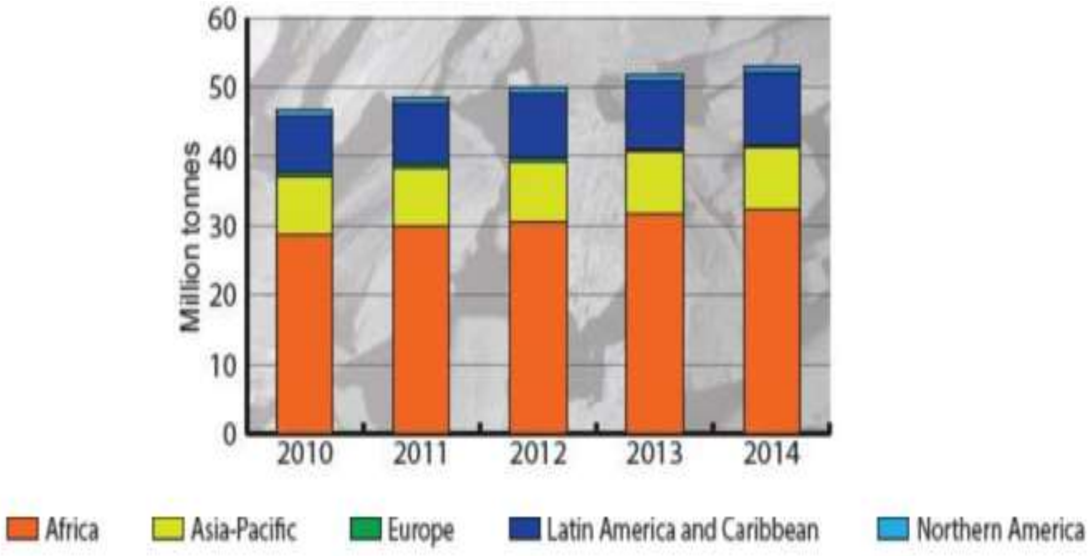



**Figure 2.1:** Global charcoal production (IIFM, 2017).

## 2.2 Charcoal supply and demand

Charcoal has the potential to provide accessible, affordable and reliable energy to thousands of households, in addition to supporting thousands of rural and urban livelihoods through income generation, providing urban–rural financial flows and contributing to the state economy. In Malawi (Africa) the charcoal sector contributes an estimated $40 million, roughly 0.5% of national GDP (Kambewa *et al.*, 2007). Yet there are large research gaps in the charcoal literature, which has led to a lack of evidence-based decision-making (ICRAF, 2015). There is good evidence that involvement in the charcoal trade can generate substantial incomes for participants (Monela *et al.*, 1993) though incomes may be unevenly distributed. Middle-men are frequently portrayed as the most exploitative actors in the value chain, yet they play essential entrepreneurial roles connecting producers and consumers (Schreckenberg, 2003; te Velde *et al.*, 2006). Highest profits often accrue to urban-based 'elite' businessmen (or women), as they typically own motorised transporting links, monopolise the trade and are politically connected (Ribot, 1998).

Charcoal producers in sub Saharan Africa are often portrayed as young and poor men (Hamilton and Hamilton, 2006; Bekele and Girmay, 2014), who benefit least from the trade because they are unorganised, are unable to access benefits and are less visible in decision-making processes (Schure *et al.,* 2013). However, recent evidence from East Africa indicates that women also participate (Butz, 2013; Jones *et al.,* 2016). According to Bard (2001), biocarbons have been manufactured by men for more than 38,000 years and are still among the most important renewable fuels in use today (Mochidzuki, 2002). In this regard, a World Bank publication (van der Plas, 1995) reaveals that demand for charcoal is increasing which cannot ve reversed easily. The growing problem of rural unemployment has also added to its demand as production of charcoal is labour intensive and is estimated to create an employment of 300-350 man-days per tetrajoule as compared to only 10 and 10-20 man-days per tetrajoule for kerosene and LPG respectively (Bhattarai, 1998).

According to Nketiah *et al.*, (1987) in Ghana most of the wholesalers are elite who may be men or women. Their main duty is to contract with wood fuel producers to purchase the product in bulk. According to the Ghana Statistical Service, 1999, an estimated 69.1% and 26% of Ghanaian households used firewood and charcoal respectively. In Mozambique, charcoal production has been found to provide a flexible source of income for rural households, making it an important seasonal diversification strategy (Jones *et al.,* 2016). However, there is still insufficient systematic analysis of the extent to which involvement in the charcoal trade contributes more widely to livelihoods, for example how it affects vulnerability and risk, capability and empowerment (Shackleton *et al.,* 2008), its seasonal contribution, and peoples' motivations for involvement in the trade. Within the charcoal literature, male charcoal transporters typically earn higher wages than women (Smith *et al.*, 2015).

Currently, millions of rural and urban people worldwide derive part of their livelihood from the charcoal value chain (Zulu and Richardson, 2013; Macqueen and Korhaliller, 2011; World Bank, 2011). Quasi open access to woodland resources, low investment requirements and low labor opportunity costs due to a lack of alternative income generating activities and low agricultural productivity make charcoal production a profitable activity for the rural population (Zulu and Richardson, 2013;

NL Agency, 2010; Kambewa *et al.,* 2007; SEI, 2002; Luoga *et al.,* 2000). Managed sustainably as a renewable resource, charcoal production could serve as a long-term income source for the poor (Ghilardi *et al.,* 2013; Falcão, 2008), alleviate poverty during the agricultural off-season and improve well-being (Schure *et al.*, 2014b; Zulu and Richardson, 2013; Arnold *et al.,* 2006; Angelsen and Wunder, 2003). Several studies have investigated charcoal supply chains and their political economies (Minten *et al.,* 2013; Kambewa *et al.,* 2007; Brouwer and Magane, 1999; Ribot, 1998) showing highly informal institutional arrangements. Chavana (2014) concluded that charcoal producing community members can create highest benefits among all groups involved in the value chain due to their low production costs. Also van der Plas *et al.,* (2012) calculated that 53% of total charcoal income goes to producers (and 9% to transporters, 17% wholesalers and 21% to retailers) and concluded that a considerable share of the charcoal benefits remain in rural areas. Likewise, Brouwer and Magane (1999) estimated that considerable revenues benefit rural areas. However, none of the studies distinguished variability between producers e.g: between local village producers and migrant full-time workers who are contracted by large-scale urban operators and are not members of the local community, a common phenomenon in Southern Mozambique (Atanassov and Mahumane, 2012; Puna, 2008).

## 2.3 Socio-economic Importance of Charcoal

Bhattarai (1998) concluded that charcoal production is a labor-intensive process. A large number of people are employed in different phases of charcoal making and distribution: in collection; in sizing the wood; in preparation of kilns for converting wood into charcoal; in loading the wood into the kilns and unloading charcoal after conversion; in unloading, bundling, packaging and transportation; and in marketing and utilization.

Some of the socio- economic benefits derived from wood fuel production enumerated by Earl (1974) includes: creation of employment, provision of money for the rural sector, savings in foreign exchange, provision of chemical fuel for chemical industry, increasing the total profitability of the forest and Provision of smoke less fuel for cities (charcoal).

According to Lawrence Amoh-Anguh (1998), the woodfuel sector employs many men, women and children in both rural and urban areas, offering both temporal and permanent employment opportunities. It is important economically because it offers immediate sources of employment to those found in the chain of distribution (exploiters, wholesalers, retailers). Formal-sector employment opportunities include direct employments comprising jobs involved in tree plantation, in the carbonization processes, transportation of wood fuel from the point of production to the prospective consumers and other indirect job opportunities generated as a result of expenditures related to the wood fuel cycle (Faaij, 1997).

Bhattarai (1998) reveals that in India 3-4 million people are believed to be involved in woodfuel trade, which makes it the largest source of employment in the energy sector. In Gujarat State of India, charcoal making is an established activity, which is providing employment and income to the poor in the drought-prone areas. It is reported that 34% of the sales price in the local charcoal market was the cost of labor, and 14% contractor, 6% private material, 11% transportation, and 31% return to the cooperatives society of the plantation (RWEDP, 1993a). In RWEDP (1996), it is stated that in the case of fuelwood, the owners of trees and charcoal producers receive around 50% of the final sales price, transporters 10-15%, and traders around 30-40%. He also state that in terms of the economic gain, it is stated that the farmers who produced charcoal got a 14% higher return compared to those who sold fuelwood. Besides, charcoal making was also a relatively easy job compared to converting the thorny *Prosopis* trees into fuelwood. A study by IIM Ahmedabad of charcoal makers in Gujarat (IIM, 1993) showed that the simple operation of converting prosopis into charcoal, which can give employment to thousands of people.

According to RWEDP (1991a), in places where charcoal making and trade is an illegal activity (e.g. Nepal), the producer of charcoal seems to have a greater share of the income due to fewer intermediaries involved in the flow process. In the Philippines, the joint UNDP/World Bank ESMAP study of 1992 estimates that over 830,000 households are involved in woodfuel related business, ranging from gathering to trade (536,000 in gathering, 158,000 in charcoal making and selling, 40,000 as rural traders and another 100,000 as urban traders).

## 2.4 Method of wood charcoal production

The production of charcoal involves various processes and techniques. Earl (1972) mentioned and described the various carbonation methods and the processes that are employed in the production of charcoal. Among the carbonation methods are: Kilns, Retort, Continuous kilns, furnaces. The modern carbonization methods evolved from a rudimentary earth- covered kiln and pits (earth mound) which was the earliest means of making charcoal. Charcoal is part of a range of fuels for domestic use that needs to be incorporated into any programme to rationalize energy resource use in tropical countries (Girard, 2002). In terms of employment, if not in financial terms, its importance is comparable to that of cash crops (Matly, 2000). Banning the production and/or marketing of charcoal, as has sometimes been done (for example in Mauritania and Kenya), has proved counterproductive: bans do not in fact reduce production, but simply drive producers underground, thereby precluding proper control of production procedures (FAO, 1993).

While a variety of charcoal kilns exists, the most common are rectangular in shape, and vary in size from as small as 5 $m^3$ to as large as over 80 $m^3$ (Ranta and Makunka, 1986; Chidumayo and Chidumayo, 1984; World Bank ESMAP, 1990; Sawe and Meena, 1994). What determines the size of the kiln is the amount of wood and labour available to the producer. The kiln size should be such that the producer is able to work with (Boutette and Karch, 1984). Too large a kiln may be too difficult to cover and manage, especially for an inexperienced producer, while a small kiln has a power thermal stability and may produce less charcoal and also of lower quality. The size of the wood available is another factor that determines the kiln size. A kiln of 5-10 $m^3$ for example, is too small for logs having an average diameter of

20cm (Ranta and Makunka, 1986). Therefore, amount of charcoal produced from a kiln depends on several factors which are related to the carbonization efficiency.

Trossero (1991) also evaluated the charcoal making technologies prevailing in the developing countries. Systems using internal generation of heat could be further divided on the basis of their method of combustion. The three possibilities existed – earth kiln, which was lowest in cost, bricks or masonry kiln of intermediate cost and steel kiln which was the most expensive.

## 2.5 Wood charcoal utilization

There is a kind of ladder of energy sources in the urban areas: from firewood at the bottom, through charcoal, kerosene and LPG, to electricity at the top (Kammen and Lew, 2005). People generally climb this ladder as their income increases. Therefore charcoal, which is infrequently used in the rural areas because of availability of free wood, is quite popular in urban areas because of higher income and other factors such as its lightness and non-smoking nature (FAO, 2000). Growing urban populations are relying on the more compact charcoal as the primary source of urban cooking energy (Kammen and Lew, 2005) with many transitioning from firewood to charcoal as the cost of wood increases in urban areas (Barnes *et al.*, 2002). The Charcoal potential in Southern Africa (CHAPOSA) study estimated that consumption of charcoal grew during 1990 to 2000 by 80 percent in both Lusaka and Dar es Salaam.

According to the FAO (2000), as cited by Broadhead *et al.,* 2001, the quantities of charcoal needed by 2020 and 2030 in Africa alone is estimated at 38.4 and 46.1 million tons respectively (**Table 2.2**). This shows that charcoal will continue to be a key source of household's domestic and commercial cooking energy form for most rural families in the developing world. In Asia, despite declining consumption, there will still be an estimated 1.7 billion users in 2030, while 70 million would be in Latin America (IEA, 2002). Barnes *et al.,* 2002 estimates that charcoal consumption is often growing faster than firewood consumption. Kammen and Lew (2005) reported that in 1992, 24 million tones of charcoal were consumed worldwide where developing countries account for nearly all of this consumption, and Africa alone consumes about half of the world's production. Charcoal production has increased by about a third from 1981 to 1992, and is expected to increase with the rapidly growing population in the developing world. Ribot, (2006) stated that LPG penetration is increasing in rural areas, households using LPG are still using as much or more charcoal than households which only use charcoal.

On a global scale, Broadhead *et al.,* (2001) reported that out of 2 billion people who depended on wood for fuel mostly in developing countries, only 96 million were able to satisfy their minimum energy needs for cooking and heating through importations and exportations of charcoal.

**Table 2.2:** FAO Projections of Charcoal Consumption (million tons) to 2030 in the Main Developing Regions

| Years | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| South Asia | 1.3 | 1.6 | 1.9 | 2.1 | 2.2 | 2.4 | 2.5 |
| South east Asia | 0.8 | 1.2 | 1.4 | 1.6 | 1.9 | 2.1 | 2.3 |
| East Asia | 2.1 | 2.3 | 2.3 | 2.2 | 2.1 | 2.0 | 1.8 |
| Africa | 8.1 | 11.0 | 16.1 | 23.0 | 30.2 | 38.4 | 46.1 |
| South America | 7.2 | 9.0 | 12.1 | 14.4 | 16.7 | 18.6 | 20.0 |

Source: Broadhead *et al.,* (2001)

As indicated in **Table 2.3**, the growth of some countries requires more charcoal for domestic and commercial use. It is estimated that for every 1 percent increase in urbanization, there is a 14 percent correspondent increase in charcoal consumption (UNFPA, 2009). Table 2.3 Principal countries importing and exporting charcoal.

**Table 2.3:** Status of charcoal export and import in different countries of the world.

| Importing countries | Quantity (Tonnes) | Exporting countries | Quantity (Tonnes) |
|---|---|---|---|
| Saudi Arabia | 12,000 | South Africa | 10,000 |
| Netherlands | 14,000 | Portugal | 12,000 |
| Sweden | 16,000 | Philippines | 18,000 |
| United Kingdom | 21,000 | Malaysia | 19,000 |
| Bahrain | 27,000 | Singapore | 28,000 |
| Japan | 34,000 | Sri Lanka | 30,000 |
| France | 57,000 | Indonesia | 36,000 |
| Malaysia | 61,000 | Thailand | 70,000 |
| West Germany | 64,000 | Spain | 90,000 |

Source: FAO, (2000).

As per the UN statistics (2016) (Fig. 2.2), the charcoal consumption in India has increased significantly from the year 2007 onwards, with respect to the period 2004 to 2006.

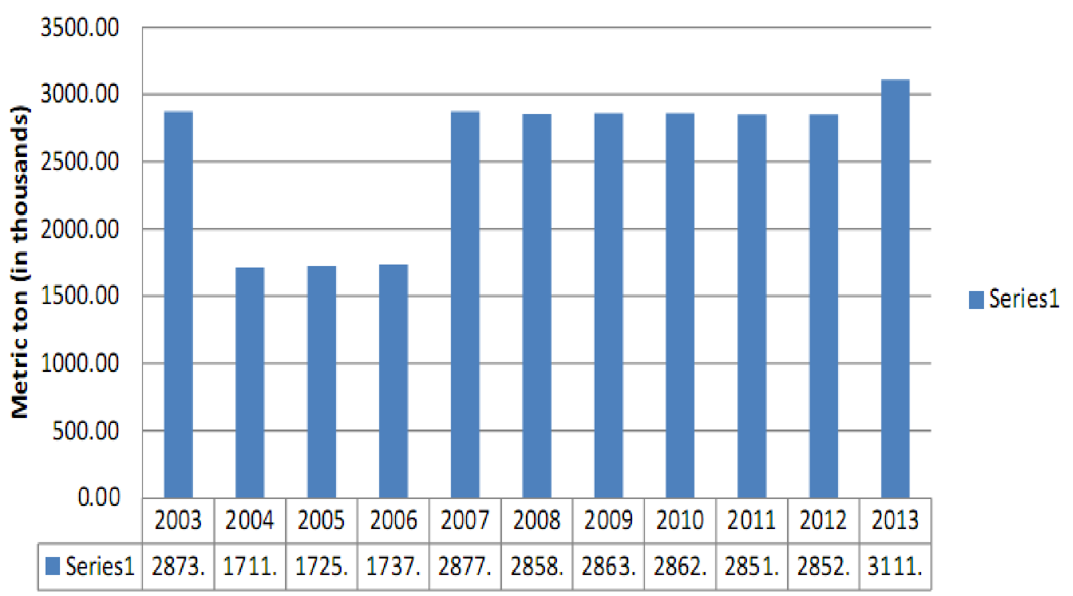



**Figure 2.2:** Total charcoal consumption in India

## 2.6 Charcoal quality

According to Girard (2002), when charcoal comes to be used as cooking fuel in a given country, the speedy introduction of procedures encouraging the use of light charcoal (sale by weight, quality-based prices, control over the species used, etc.) could limit overexploitation and encourage production from plantation species, to the considerable benefit of the environment and consumers.

Charcoal has a heating value twice as much as fuelwood on an equal weight basis (Bhattarai, 1998). The natural water content in green wood is always high; even hardwood species contain as much as 50-60% water. When trees are cut, the water content in wood starts decreasing rapidly and reduces to 30-40% within a short time even in damp climates. And 3-6 months after the harvest it may go down to only 10-20%, on an air-dried basis. The net calorific value of oven-dried wood is commonly considered as 18.8 MJ/kg (megajoule per kilogram), but it is only 15-16 MJ/kg on air-dried basis (Foley, 1986). RWEDP (1997a) suggests only 13.6 MJ/kg for air-dried wood. The following table summarizes the general features of wood charcoal (Earl, 1975).

**Table 2.4:** General features of wood charcoal (Earl, 1975).

| | |
|---|---|
| Yield by weight | 20-30% of the dry weight of wood |
| Yield by volume | 50% of volume of wood |
| Percentage yield of lump charcoal | 75-90% |
| Hardness | Varies according to the density of wood |
| Moisture | 1-16% |
| Volatile matter (mainly hydrocarbons) | 7-30% |
| Fixed carbon | 80-90% |
| Sulphur | Trace |
| Ash | 0.5-10% |

## 2.7 Effect of carbonization temperature on charcoal yield and quality

According to World Bank, (1990), the relationship between the carbonization temperature and charcoal yield is inverse i.e. the higher the temperature, the lower the yield. Since it is often difficult to achieve and maintain high temperatures during carbonization in an earth kiln, charcoal is usually produced at relatively lower temperatures of 300- 600 °C. Such charcoal has low calorific values, is corrosive due to its content of acidic tars and produces smoke when burnt (FAO, 1987). Producing charcoal at much high temperature, however, may lead to it being friable, thus not being easy to handle and transport. Carbonization temperatures of 450-500 °C give an optimum balance between friability and the desire for high fixed carbon content (FAO, 1987). Generally good quality charcoal has a fixed carbon content of about 75%. Modifications in the micro-structure of wood from *Prosopis nigra* as a function of temperature were studied by scanning electron microscopy (SEM) (Pasquali *et al.*, 2002). The results showed that the basic anatomic structure of wood remains almost unchanged in the working temperature range.

Sensoz and Can (2002) investigated the effect of temperature, heating rate and pyrolysis atmosphere on the pyrolytic product yields of Turkish pine *(Pinus brutia* Ten.) using a laboratory-scale fixed bed reactor. They concluded that the significant pyrolytic conversion in the temperature interval of 450 – 500 °C was due to the rapid devolatization of cellulose and hemicellulose. Conversion of waste olive wood to value added charcoal was reported by Figueiredo *et al.,* (1989a). Figueiredo *et al.,* (1989b) studied the pyrolysis of holm-oak wood sawdust. Considering the quality of the charcoal and the heating value of the gases produced, they concluded that the optimal pyrolysis temperature was 600 °C. Effect of carbonization temperature on charcoal yield and quality produced from some tropical fast-growing and short-rotation forest tree species viz. *Gliricidia sepium, Leucaena leucocephala* and *Gmelina arborea* were evaluated by Fuwape (1996a) and found that out of the three species, *G. sepium* yielded the highest yield of charcoal. Yield and volatile matter content of the charcoal were found to decrease with an increase in carbonization temperature while there was an increase in the percentage of fixed carbon content.

## 2.8 Effect of moisture content of wood on charcoal yield

The higher the wood moisture content, the greater the pre-carbonization heat required to dry the wood (World Bank, 1990; Commonwealth Science Council, undated; FAO, 1987). Since the transformation of water to steam (during drying) requires heat which is produced by the burning of part of the wood charge, the higher the moisture content, the larger the amount of wood burnt. Charcoal yield is, therefore, reduced proportionally. Another aspect associated with wood of high moisture content is the cracking of wood during carbonization (FAO, 1987). During the drying of wood, the water within its biological structure vaporises into steam, becomes pressurised and bursts the wood. Charcoal thus forms fines and has many cracks, and by the time it reaches the consumer the useful amount may have dropped significantly. Ranta and Makunka (1986) recommended a minimum drying time of 5 – 6 weeks after felling trees.

## 2.9 Skill of the producer in relation to charcoal yield

The Food and Agriculture Organization (FAO) has estimated that total charcoal production in 1992 was 24 million tons, where traditional production techniques lead to low conversion efficiency. Using the FAO dry weight conversion efficiency of 23%, one finds that about 100 million tons of wood are annually cut for charcoal production. The skill of the producer is crucial particularly during carbonization as the kiln has to be properly managed if a high yield of good quality charcoal is to be obtained. Supply of dry wood for charcoal production from a *Eucalyptus cloeziana* plantation in Brazil was assessed by Lopes *et al.*, (1998). Charcoal yield was 34.4% and the mean fixed carbon content was slightly below 77%.

Schenkel *et al.*, (1998) evaluated the performance of mound kiln carbonization process used throughout the developing world. From a comparison of various indicators of the different processes, they showed that the mound kiln carbonization process was as efficient as improved processes and was characterized by mass yields ranging from 20% - 30% as dry weight basis and by fixed carbon contents above 75% as dry weight basis. Antal *et al.*, (1996) described a practical method for manufacturing of high quality charcoal from biomass that realizes near-theoretical yields of 42% - 62% with a reaction time of about 15 min to 2hr depending on the moisture content of the feed. With 45% transformation efficiency, this process would consume only 2.2 kg of biomass per kg of charcoal as against 5 kg of dry biomass per kg of charcoal produced in a conventional kiln operating at 20% efficiency. Antal *et al.,* (2000) further tried to increase the yield of charcoal by developing a new process where the yield of charcoal attained the theoretical value predicted to exist when thermo-chemical equilibrium is realized. They obtained high yields of fixed carbon at 1.0 MPa from a wide variety of agricultural wastes and charcoal yields and fixed carbon content obtained from some biomass feeds such as kukui nut shell, bamboo and *Leucaena* wood attained the theoretical values predicted to exist when thermochemical equilibrium was realized at 1.0 MPa.

Charcoal being one of the major sources of domestic energy in most African countries, the potential of indigenous trees and shrubs for sustainable charcoal production in Laikpia, Kenya was explored by Okello *et al.,* (2001). *Acacia drepanolobium* was investigated for sustainable charcoal production and found that woody biomass was strongly related to stem diameter while efficiency of charcoal production from earthen kilns and was in between 10% - 18%. Connor and Viljoen (1998) discussed ways for improving the efficiency of charcoal production with particular reference to kilns. They pointed out that existing large-scale charcoal producers use kiln designs and operating practices that give reasonable yields and efficiencies.

In a study, Shah *et al.,* (1992) aimed at understanding and upgrading the process of wood to charcoal conversion, commercial partial-combustion kiln (PCK) was used for experimental carbonization that yielded a mass efficiency of 15 -30% (based on initial wet mass). Khristova and Vergnet (1993) assessed the suitability of two unusual biomass materials *viz. Hibiscus sabdariffa* var. *sabdariffa* stem and *Calotropis procera* wood of Sudan as potential raw material for charcoal production. Physical properties and chemical constituents of these two biomass materials were determined. Proximate analysis of charcoals obtained from these two tree species revealed that 79%, 86.5%, fixed carbon content respectively with gross heating value of 30.3 MJ/kg for *H. sabdariffa* and 32.4 M/Jkg for *C. procera* charcoals. Connor and Viljoen (1995) reviewed wood carbonization and emphasized on the need to improve the efficiency of the present charcoal production techniques for increasing charcoal yield. They also reported that external conditions such as temperature, heating rate and pressure were also important as far as their influence on wood carbonization was concerned.

Density and permeability are two major physical properties of wood that could be expected to influence significantly the migration rate of volatiles and thereby affecting final char yield during carbonization. Initial experiments by Connor *et al.,* (1996) involving closely related tree species revealed a fair correlation between density of wood and charcoal yield. But further investigation with different wood species showed that co-relation between density and charcoal yield was tenuous. Early results for wood samples from several *Eucalyptus* species grown in Brazil confirmed the lack of relationship, between density and charcoal yield but suggested a stronger link between permeability and charcoal yield. Ishengoma *et al.,* (1997) reported the quality of charcoal produced from *Leucaena leucocephala* in earth kilns in Tanzania. Though density of *L. leucocephala* charcoal was lesser but its calorific value and ash content were found to be better than those of the commercial grade charcoals. Wood quality and charcoal quality of nine *Eucalyptus* species were evaluated by Trugilho *et al.,* (1997a) with a view to identify the highly potential genotype for use as energetic raw material. They further studied these species to evaluate their wood quality for charcoal production (Trugilho *et al.,* 1997b). The co-relation between a group of variables related to charcoal characteristics and a group of variables related to wood quality was studied, the canonical correlation showed that the properties of wood that are highly associates with charcoal quality were the high basic density, low ash content, high lignin content, thickness of fiber walls and fiber wideness. Based on this observation, they suggested that these variables must always be analysed conjunctly in studies related to charcoal productions.

The most important aspect considered is the wood's lignin content. High lignin content gives a high charcoal yield (FAO 1987; Pagama, 1993). Mature or old growth trees are highly lignified and are therefore better to use than young trees.

## 2.10 Physico-chemical properties of charcoal

The most important properties of charcoal are those that determine its quality. *Charcoal quality* is defined in terms of moisture content, volatile matter, fixed carbon and ash. These are termed as chemical properties. Physical properties relate to charcoal's resistance to fracture. Charcoal straight from the kiln has very little moisture, usually less than 1% (FAO, 1987). Thereafter, it absorbs moisture of between 5 - 10% and when not properly stored, it may contain moisture of up to 15% due absorption of rain water. Moisture negatively affects the combustion properties of charcoal. It reduces its calorific value since the water in it has to be evaporated during burning. Therefore, the drier the charcoal, the better its combustion characteristics. To determine the moisture content of charcoal, a known mass of charcoal is heated at constant temperature (usually 105 °C for 24 hours) and thereafter weighed. The mass difference is the mass of water which is expressed as a percentage of the original charcoal mass, either on air or oven dry basis.

Volatile matter includes all liquid and tarry residues not fully driven off during the process of carbonization. The longer the process of carbonization, coupled with higher temperatures, the lower the content of volatile matter. If carbonization time is short and temperature is low, the value of volatiles increases. Volatile matter approaches zero at high temperatures of about 1000 °C (FAO, 1987). Volatile matter in charcoal varies from less than 5% to about 40% and is measured by heating, in absence of air, a weighed amount of dry charcoal at 900 °C to constant mass. The mass loss being the volatile matter content, while the remains is ash. Charcoal with high amounts of volatiles is easy to ignite, burns with a flame but most likely with much smoke and is more hygroscopic, less friable and thus producing less fines during transportation and handling. When volatiles are low, charcoal is difficult to ignite, but burns cleanly without a flame. Commercial charcoal has a volatile content of about 30% or less (FAO, 1987). Fixed carbon of charcoal ranges from a low of

50% to a high 95% (FAO, 1987). Charcoal, therefore, consist mainly of carbon. The fixed carbon content is the difference, in percent, from 100 of the other constituents (moisture, ash, volatiles).

The ash content depends on the species of wood, amount of bark included in the wood put into the kiln and the amount of earth and sand contamination. It varies from 0.5% to more than 5%. Good quality charcoal has about 3% ash content (FAO, 1987).

## 2.11 Physical Properties

Physical properties of charcoal relate to its strength or ability to resist fracturing during handling. Charcoal strength is determined by measuring the resistance of the charcoal to shattering or breakdown by allowing a sample to fall from a height onto a solid steel floor or tumbling a sample in a drum to determine size breakdown after a specified time (FAO, 1987).

**Table 2.5:** Desirable Characteristics of Charcoal for Blast Furnaces in Brazil (FAO, 1983)

| **Chemical and Physical Composition of Charcoal Dry Bass - by weight** | **Range** | | **Yearly Average** | **Charcoal considered good to excellent** |
|---|---|---|---|---|
| | **Max.** | **Min.** | | |
| Carbon | 80% | 60% | 70% | 75-80% |
| Ash | 10% | 3% | 5% | 3-4% |
| Volatile matter | 26% | 15% | 25% | 20-25% |
| Bulk density - as received (kgs/m³) | 330 | 200 | 260 | 250-300 |
| Bulk density - dry | 270 | 180 | 235 | 230-270 |
| Average Size (mm) - as received | 60 | 10 | 35 | 20-50 |
| Fines content - as received (-6.35 mm) | 22% | 10% | 15% | 10% max. |
| Moisture content - as received | 25% | 5% | 10% | 10% max. |

However, depending on the type of wood off-cut used to make charcoal, they burn cleaner in cook stoves than briquettes and firewood. Charcoal commonly used for domestic purposes may have a net calorific value of 28 MJ/kg (Foley, 1986). That means its net energy value is roughly twice as much as for air-dried fuelwood. This big difference makes charcoal cheaper to transport over a longer distance compared to fuelwood. Kataki (2005) reported that by converting fuelwood into charcoal one could benefits from reducing the transportation cost per MJ. On the other hand, by converting wood into charcoal one also loses a substantial amount of energy. If the recovery (or yield) of charcoal is 20% of the initial weight of the air-dried wood, the conversion ratio is 5:1. This ratio may vary between a high 6:1 to a low 4:1, depending upon the method used. The traditional practice of charcoal making in open pits may yield a lower amount of charcoal compared to improved charcoal kilns. The average conversion ratio of 5:1 means that 5 kg of air-dried fuelwood is burnt to produce one kg of charcoal. Five kg of air-dried wood is equivalent to 75 MJ (assuming an energy content of 15 MJ/kg), so when this produces 1 kg or 28 MJ in the form of charcoal, there will be a net energy loss of 47 MJ (or about 62%). Part of the energy loss during the charcoal making process is compensated during end use, because charcoal stoves have higher efficiencies than fuelwood stoves (average efficiency of 30% for charcoal stoves against only 10-15% of untended open fire or tripod).

Yatim and Hoi (1987) evaluated the quality of charcoal from various types of wood. The analysis of charcoal for their fixed carbon, ash, volatile matter and moisture contents produced in beehive kiln from rubber wood, *Acacia*, *Eucalyptus* and pine and subsequent comparison of their properties with those of the charcoals from mangrove woods indicated similarity. They concluded that charcoal produced from these tree species were suitable for industrial use. The possibility of thermo-conversion of over-matured and wilt diseased coconut palms of different age groups to charcoal was investigated by Gnanaharan *et al.*, (1988). They used a portable type 'Tongan kiln' to produce charcoal from stem wood of these palms. Comparison of the results of proximate analysis i.e. fixed carbon, volatile matter and ash contents and yield of charcoal from these two types of palms (over-matured and wilt diseased) showed no significant variation.

Pontinha *et al.,* (1992) carbonized the woods and the charcoals obtained from logs of first and fourth thinnings of *Pinus caribaea* var. *hondurensis* and *Pinus oocarpa* were analysed for their physical and chemical properties and charcoal made from pine wood materials and 7-yr-old *Eucalyptus grandis* were compared. Comparison of the results revealed that though *Pinus* spp. Had better chemical properties than that of *E. grandis,* the charcoal obtained from *E. grandis* had higher values of apparent density and lower values of bulk density than that of *Pinus* spp. Maschio *et al.,* (1992) reviewed the process of pyrolysis as a promising route for biomass utilization. They reported that fast pyrolysis gave low charcoal yield and high yield of a medium BTU gas rich in hydrogen and carbon monoxide.

Thermo-chemical conversion of *Acacia* and *Eucalyptus* was studied by Kumar *et al.,* (1992) and found that slow carbonization resulted in higher char yield than rapid carbonization. The char yield from *Eucalyptus* wood samples was greater than that from *Acacia* wood. The carbon content of *Eucalyptus* wood char was found to be little higher than that of *Acacia* wood produced under similar carbonization condition, which may be due to the relatively higher lignin content of *Eucalyptus* wood. Calahorro *et al.,* (1992) investigated the possibilities of production of charcoal by carbonization of wastes generated during the olive grove *(Olea europea* L.) prunning. They aimed at studying the quality of charcoal obtained from different parts of the olive tree by pyrolysing at 6000 °C in a dynamic atmosphere of nitrogen or in an uncontrolled atmosphere of air. They remarked that characteristics of final product of carbonization depended to a greater extent on the nature of starting material and the temperature of pyrolysis than on the kind of atmosphere in which pyrolysis was carried out.

Lim and Lim (1992) studied the carbonization of oil palm trunks at moderate temperature and reported a non-dependence of holding time on quantity and quality of charcoal produced. From the study, they concluded that oil palm trunks are not suitable for carbonization as the charcoal produced showed low caloric content and high ash content. In another experiment, Lim (1993) carbonized the cocoa wood prunnings at higher temperature ranging from 6000 - 8000 ºC. The proximate analysis of the charcoal thus produced and that of the raw wood revealed a clear dependence of yield, volatile matter and fixed carbon content on terminal temperature. However, no clear trend of variation in the ash content and moisture content of charcoal produced at various temperatures was observed. He also found that there was very small incremental increase in the fixed carbon content' after achieving a terminal temperature range of 650 - 700 °C, and therefore he had suggested that for industrial scale charcoal production from cocoa wood, a carbonization temperature ranging from 650 - 700 °C is sufficient when heating rates of few degree centigrade are employed.

Lim *et al.,* (1994) further investigated the physical properties and burning characteristics of cocoa wood charcoal. They reported that the quality of cocoa wood charcoal was quite comparable to those of other commercial grade charcoals. Results of their study revealed that density of cocoa wood charcoal is lower than those of most commercial charcoals while its friability and calorific content were comparable to mangrove wood charcoal. They opined that cocoa wood charcoals were no way inferior to other commercial grade charcoals as far as their physical properties and burning quality were concerned.

Rockrose (*Cistus ladaniferus* L.), a woody shrub was studied by Gomez-Serrano *et al.,* (1993) as a potential raw material for manufacture of charcoal and activated carbon. The wood composition and calorific value were found to be similar to other woods. Fuwape (1993) reported the combustion related properties *viz.* moisture content, specific gravity and percentages of carbon, hydrogen, oxygen, nitrogen, sulfur and ash in wood as well as in charcoal from two agro-forestry tree species *Leucaena leucocephala* and *Tectona grandis.* He reported significant differences in the moisture content, specific gravity and percentage elemental composition and ash content in wood and charcoal produced from the two species.

## 2.12 Environmental impact of wood charcoal production and its use

There is the tendency in many countries to give more prominence to environmental issues in development than the socio-economic issues thereof. For some time now social issues of development activities have been relegated to the background in the analysis and policies of countries (Ghai, 1992). Thus the impact of development, transfer and adoption of agricultural or forestry and most land-use activities have been based on the biophysical environment of the targeted group. This has strengthened studies and research on environmental related factors such as land, soil and trees (Ghai, 1992).

Therefore, broader analyses of the charcoal trade tend to focus on the negatives, such as the correlation of unregulated production and environmental degradation (Chidumayo and Gumbo, 2013; Rembold *et al.,* 2013), detrimental health impacts (Bautista *et al.,* 2008; Johnson *et al.,* 2011) and negative livelihood impacts from enforcement activities (Smith *et al.,* 2015). Adverse impact that are already apparent but which would increase if the trend continues are soil erosion, less biomass available for all other uses, traditional economic forest products such as fruits, nuts, medicinal trees becoming scarce, and more land being opened for cultivation but fall in agricultural productivity. Currently, little is known on the dynamics of charcoal production in terms of ecological and socio-economic impacts. If managed effectively, charcoal is a sustainable energy source and can contribute substantially to reducing carbon emissions and greenhouse gases (Iiyama *et al.,* 2014).

The initial review of literature indicates that the most used wood species like *Prosopis juliflora* (Vilayati Babool) has been reported to have some environmental hazards such as adverse effects on bird habitats, soil quality etc. (Tiwari, 2008). It is also found in the investigation that the charcoal is illegally produced in the Government land and mixed with the other wood species in the state of Gujarat, India. To control this problem, the Government run Gujarat Forest Corporation has started producing the charcoal itself (Anjan Kumar Prusty, 2009).

## 2.13 Effect on soil properties

It is documented that in the process of charcoal burning the magnitude of heat released during these soil heating processes are similar depending on the period or wood load in the piles, and could influence soil properties (Oguntunde *et al.*, 2004; Glaser *et al.*, 2002; Mataix-Solera *et al.*, 2002). In the study of a tropical watershed in Indonesia, Ketterings *et al.*, (2000, 2002) reported that severe burning associated with these processes have a drastic effect on soil texture, color, mineralogy and other soil properties. Oguntunde *et al.*, (2004) observed a significant decrease in clay fraction and corresponding increase in sand content in severely burnt soils, which could result in poor water holding capacity (Ulery and Graham, 1993).

The effects of the heating processes on soil are a result of the burning severity, which is determined by the peak temperatures and duration of a fire (Certini, 2005). Low to medium fire severity resulted in darkening of the topsoil while high-severity fires (> 600 °C) cause pronounced reddening of the topsoil, accompanied by an increase in both Munsell value and chroma (Ulery & Graham, 1993; Ketterings & Bigham, 2000). In a review on the effects of fire on forest soil properties, Certini (2005) concluded that low to moderate-severity fires result in a renovation of the dominant vegetation by the elimination of undesired species and a transient increase in pH and available nutrients in the forests, while severe fires (such as wildfires) generally lead to a significant loss of organic matter, deterioration of both structure and porosity, leaching and erosion, among other drawbacks.

This influences soil temperature, which in turn affects soil biophysical processes, such as seed germination, root growth, plant development and biomicrobial activity (Potter *et al.*, 1987). Charcoal may affect soil physical properties such as soil water retention and aggregate stability, leading to enhanced crop water availability and reduced erosion effects (Piccolo and Mbagwu, 1990; Piccolo *et al.*, 1997). Tryon (1948) studied the effect of charcoal addition on the available moisture in soil of different textures. A positive effect of 18% increase in soil water retention was observed upon addition of 45% (by volume) charcoal to a sandy soil while a decrease of about 20% was noted for a clay soil, whereas no change was recorded for a loamy soil, under the same charcoal treatment. Therefore, improvements of soil water retention by charcoal ameliorations may only be expected in coarse-textured soils or soils with large amounts of macropores (Glaser *et al.,* 2002).

Some studies have been carried out in some parts of the world on the effects of charcoal production on soil. A study carried out by Oguntunde *et al*., (2004) in Ghana observed a significant increase in soil pH, base saturation, electrical conductivity, exchangeable Ca, Mg, K, Na, and available P in the soil at a kiln site as compared to the adjacent soil. Giller (2001) noted that charcoal additions not only affect microbial population and activity in soil, but also plant- microbe interaction through their effects on nutrient availability and modification of habitat.

Several recent studies have shown that charcoal has the potential to greatly enhance soil fertility. Amazonian forest soils amended centuries ago with charcoal and manure still maintain some of the highest biodiversity and productivity of any soils within the Amazon basin (Glaser *et al.,* 2001, 2002; Mann, 2002). In boreal forest soils, charcoal was shown to enhance N cycling by ameliorating the inhibitory effects of litter extracts from late-successional species, which in turn promotes growth of early-successional species (Zackrisson *et al.,* 1996; Wardle *et al.,* 1998; De Luca *et al.,* 2002; Berglund *et al.,* 2004). Recently, De Luca *et al.,* (2006) found that the addition of wildfire-formed charcoal to ponderosa pine forest soils increased nitrification rates. Charcoal may enhance soil fertility through a variety of mechanisms. Increased N turnover may occur by charcoal sorption of high C: N organic molecules from the soil solution (Zackrisson *et al.,* 1996; Wardle et al. 1998; Glaser *et al.,* 2002), resulting in reduced microbial N immobilization and higher net mineralization and nitrification rates. In addition, charcoal may remove specific groups of organic molecules, including polyphenol or monoterpene compounds that are thought to inhibit nitrification (Rice and Pancholy 1972; Zackrisson *et al.,* 1996; De Luca *et al.,* 2002; Berglund *et al.,* 2004). Sorption of organic molecules, along with the gradual breakdown of charcoal, may initiate humus formation and, thus, enhance long-term soil fertility (Glaser *et al.,* 2002). Charcoal may also enhance soil fertility by creating habitat for microbes within its porous structure (Pietikainen *et al.*, 2000b).

Fontodji *et al.*, (2009) revealed that the soil physical, chemical and microbial properties were altered after charcoal production. The organic matter was destroyed; it is higher at the unburnt plot level than inside the kiln. The soil pH increased at the kiln level by the provision of rich ash bases during the carbonization. Fire increased the permeability at the kiln level by raising the bulk density and the total porosity of soil. Glaser and Zech (2002) concluded that charcoal residues and charred biomass left on the kiln sites has been also found to serve to ameliorate and, improve the fertility of tropical soils by direct nutrient the addition and retention. According to Oguntunde *et al.*, (2004), available phosphorus, exchangeable bases, total nitrogen, organic carbon and base saturation was higher in soils of charcoal production sites than the adjacent lands. A study conducted also showed that bulk density on charcoal-site soils reduced by 9% compared to adjacent field soils.

Oguntunde *et al.*, (2004) observed that the grain and biomass yield of maize and also increased by 91 and 44%, respectively, on charcoal production sites soils as compared to adjacent farmland soil. They however, opined for the need of further research to ascertain the long-term effects of charcoal production on the soil environment and the fertility of tropical soils. Chidumayo (1994) reported generally better seed germination (30% enhancement), shoot heights (24%) and biomass production (13%) among seven indigenous woody plants on soils under charcoal kilns compared to the undisturbed Zambian Alfisols and Ultisols. Kishimoto and Sugiura (1985) found that the heights of sugi trees (*Cryptomeria japonica*) increased by a factor of 1.26–1.35, and the biomass production increased by a factor of 2.31–2.36, five years after application of 0.5 Mg charcoal/ha.

Abebe and Endalkachew (2011) concluded that as compared to adjacent soil, bulk density and clay percentage decreased significantly at kiln site but the sand fraction was significantly increased. Although the observed difference was non significant, water holding capacity and silt percentage was reduced at charcoal production site. At kiln site, pH was increased whereas electrical conductivity was increased by more than 6 times. Similarly, organic carbon, total nitrogen, available phosphorus, cation exchange capacity and exchangeable bases were also significantly higher at kiln site than adjacent soils.

Gebhardt (2007) also opined that the impact of charcoal exploitation on the soil micromorphology is not directly due to the combustion effects, but more to operations related to the local deforestation for wood exploitation, the preparation and management of the plots before, during and after the production phase and the domestic activities of the charcoal burners. Ogundele *et al.,* (2011) recommended that there should be further research to evaluate the influence of climate, soil characteristics, duration of time between charcoal burning and collection of soil samples, and chemical composition of wood species on the effects that charcoal production has on soil properties. The efficiency of biomass conversion into charcoal becomes important in conjunction with a newly proposed opportunity to use charcoal as a soil conditioner that improves soil quality on very acid and highly weathered soils (Lehmann *et al.,* 2002; Steiner *et al.,* 2004). This can be realized either by charring the entire aboveground woody biomass in a shifting cultivation system as an alternative to slash and- burn, coined recently as slash-and-char by (Glaser *et al.,* 2002; Lehmann *et al.,* 2002) or by utilizing crop residues in permanent cropping systems. Charcoal formation during biomass burning is considered one of the few ways that C is transferred to refractory long-term pools (Glaser *et al.,* 2001a; Kuhlbusch and Crutzen, 1996; Skjemstad, 2001). Producing charcoal for soil amelioration instead of burning biomass would result in increased refractory soil organic matter, greater soil fertility and a sink of $CO_2$ if re-growing vegetation (secondary forest) is used. A farmer practicing slash and char could profit from soil fertility improvement and C credits (if provided by a C trade mechanism to mitigate climate change), providing a strong incentive to avoid deforestation of remaining primary tropical forests.

## 2.14 Forest resources and health

Charcoal leads to considerable deforestation, which is now one of the most pressing environmental problems faced by the country. Deforestation has negative implications both for the local and the global environment. Also, deforestation leads to reduction of natural resources on which the poor depend, and land degradation, contributing to the downward spiral of poverty.

According to Girard (2002) charcoal is often traditionally made from species that yield a dense, slow-burning charcoal. These species are slow growing and are therefore particularly vulnerable to overexploitation. According to Girard (2002), the carbon content of wood and charcoal is 50 and 90 percent respectively, giving the following carbon equivalents:

- 1 000 kg of wood → 500 kg of carbon;
- 250 kg of charcoal → 225 kg of carbon;
- 150 kg of charcoal → 135 kg of carbon.

When a tonne of wood is carbonized, 365 kg are released into the atmosphere with a poorly managed technique and 275 kg with improved methods. Improved technique thus prevents the emission of 90 kg of carbon per tonne of carbonized wood, equivalent to 300 kg of carbon or 1.1 tonnes of $CO_2$ per tonne of charcoal consumed.

The impact of charcoal production on forest land has always been a matter of concern for environmental activists. Chidumayo (1993) studied the recovery of Miombo woodlands following clearance of woodland for carbonization. Though charcoal production removed 50% of the total woody biomass, clearing of successive regrowth Miombo did not appear to affect productivity. However, the sites where carbonization was carried out, the soil structure, seedlings and root stocks were found to be destroyed or damaged. Monela *et al.,* (1993) conducted a survey to assess the socio-economic aspects of charcoal consumption and its impact on the environment along the Dar es Salam - Morogoro highway in Eastern Tanzania, concluded that heavy charcoal consumption near the growing city of Dar es Salam promoted the charcoal business with a positive impact on households but at the expense of environmental protection. Cutting of wood for fuelwood and charcoal has been cited as a major cause of deforestation by various workers. But Openshaw (1996) contradicted this point and opined that the change of land use pattern was the major cause of deforestation. He suggested that rather than viewing the use of wood as a cause of deforestation and one of the reasons for global warming, the management of existing tree resources, the planting of trees and above all the expanded use of wood, especially wood energy could be a major strategy to slow down and eventually reverse the production of excess green house gases. Hofstad (1997) constructed a dynamic model of deforestation linking marginal cost and demand of charcoal, the increment of woody biomass within the wedge will supply little charcoal for many years because woodland density did not affect production costs. Therefore, reduced demand for charcoal and shift to other forms of energy was the controlling factors of deforestation.

During the process of carbonization, water and other substances in the wood are driven off as heat and smoke. After drying the wood starts to char spontaneously thereby generating more heat which raises the kiln temperature to about 600- 700°C. At this stage the yellow and hot kiln smoke into a large extent made up of acetic acid, methyl alcohol and tar (Boutette and Karch 1984). The kiln temperature drops after the completion of the thermal decomposition process and the charcoal may then be recovered with a fork. Charcoal fines and the soil that made up the earth wall are abandoned at the kiln site. The charcoal spots cover about 3.6% of the cut-over area and on average the charcoal fines make up 3% of the total charcoal produced (World Bank 1990). On a dry weight basis the wood to charcoal conversion rate is 23% (Chidumayo 1991a). The current methods of charcoal production require vast amounts of resources for relatively little return, compounded with low replanting rates and poor land management practices that have been identified. Customary land tenure often conflicts with that of a statutory nature, preventing adequate land management practices and ultimately contributing to the widespread degradation that exists today (Benjaminsen and Lund, 2003).

The Casamance kiln is believed to be more efficient in carbonizing the wood therefore increasing the output of the kiln by 10 – 30 percent (Kammen and Lew, 2005). This increase in efficiency combined with selective logging could result in a slightly larger extraction area, but a lesser degree of environmental impact. Areas classified as Classified Forest are theoretically off limits to charcoal production, but are often times used for charcoal production (Ribot, 1999). According to USAID (2007), differing management plans call for selective logging to take place, leaving non-regenerating species and harvesting two-thirds of other species in the area, but in many instances well over 75% of the wood is harvested for charcoal production. Manga (2005) reported that in the community regulated landscape, wood is intensely harvested for charcoal production in very compact intense zones, closer to clear cutting.

The targeting of particular tree species for the production of charcoal has made charcoal production and use a major driver of forest cover depletion. Local tree species are the target for majority of the charcoal produced. Njenga (2013) notes that closed to 100 tree species are targeted by charcoal producers in Kenya, with *Acacia tortilis, A. nilotica, A.senegal, A. mellifera, A. polyacantha and A. xanthophloea* being the most preferred. Apart from these, charcoal producers also target other hardwood species like *Croton, Olea, Manilkara, Mangifera, Eucalyptus* and *Euclea*, which according to (Mugo *et al.,* 2007) are preferred due to their high density and calorific value.

A study done in Nigeria, Burkina Faso, Mali, Niger and Senegal found substantially different species compositions in farmed parkland and a nearby ecologically equivalent forest reserves (Kindt *et al.,* 2008). Tree species which do not coppice may disappear altogether. A study in Senegal noted that many tree species, particularly large trees have very few seedlings and therefore very low probabilities of regenerating naturally (Lykke, 1998). Another study in Ghana found that an important fuelwood species such as mahogany used by 80 percent of households in two villages in the savannah belt during the past decade was no longer available (Pabi and Morgan, 2002). According to Mugo and Ong (2006), unplanned, unmanaged and unsustainable charcoal production will lead to forest cover depletion especially in the drier areas characterized by very low regenerative capacity. In the context of a green economy, the negative effects of charcoal production and use are unavoidably associated to the slow growth of particular tree species that are harvested for charcoal, wasteful use of the harvested wood, environmental pollution and poor working conditions of those involved in the production process (Mugo and Ong, 2006).

De Miranda (1999) discussed the deforestation and forest degradation by commercial harvesting for firewood and charcoal in Nicaragua. He reported that deforestation appeared to be more associated with the changes of use of land from forest to agriculture and cattle ranching while forest degradation appeared to be directly associated with fuelwood harvesting for both household and industrial uses and charcoal production. He concluded that fuelwood harvesting for firewood and charcoal was not the main factor causing deforestation in the tropical dry forests of the Pacific region of Nicaragua.

Muylaert *et al.,* (1999) evaluated the technical feasibility of implementing a new method of charcoal production in Brazil and examined the environmental benefits of the method over the conventional muffle furnaces. This new muffle type furnace with external combustion chamber had higher production efficiency and this would mean utilization of less amount of wet wood for production of same amount of charcoal than conventional muffle furnace methods. This in turn, had potential to save 18.7 million tons of wet wood per year and consequently, 1.4 million hectares of land would be saved from deforestation per year. The most important point was the reduction of $CO_2$ emission. They reported that if the new type of carbonizer was used, it could reduce the $CO_2$ emission by 25.7 million ton per year. Zendersons *et al.,* (1998b) & Zandersons and Zurins (1999) described a technology developed at the Latvian State Institute of Wood Chemistry, Latvia for lump charcoal production by small and medium sized enterprises in rural conditions. They developed equipment which had provision for burning wood thermal degradation non-condensable gases and vapours for initial drying of wood. It was therefore considered to be more environments friendly and energetically self-sufficient once the process was started. In an effort to explore new raw materials for sustainable charcoal production in Brazil, Zandersons *et al.,* (2000a) evaluated the possibility of using sugarcane bagasse for charcoal production. The physical and chemical compositions of sugarcane bagasse were determined to examine its suitability for use as feedstock in industrial charcoal production. Such a reactor, according to them would also considerably improve the emission situation as it will drastically reduce the emission of noxius gases to an environmentally acceptable limit.

Carbonized materials are formally authorized for use as soil amendment material in Japan, which is using 27% of its national charcoal production (50,835 t) for purposes other than fuel, more than 30.6% of which is used in agriculture (Okimori et al. 2003). In the past Japanese farmers prepared a fertilizer called “haigoe” which consisted of human waste and charcoal powder (Ogawa 1994). Charcoal is proposed to be an important component of the man-made and exceptionally fertile *terra preta* soils in the Amazon (Glaser *et al.,* 2001b). In the SADC region, households consume about 97% of wood energy mostly for cooking, heating and cottage industries while industrial sector is the second to household sector (SADC Energy Sector 1993 in Monela and Kihiyo, 1999). Furthermore due to the anticipated steady increase in population, it is expected that actual consumption of firewood and charcoal will continue to rise to a greater extent.

Environmentalists feel that charcoal production should be stopped because of its destructive nature as presently practiced (Achard *et al.,* 2002). However, Arnold and Persson (2003) asserted that both rural and urban dwellers in some developing countries have developed a strong appetite for charcoal use. Therefore attempts to ban the production or the use of charcoal will be mostly unsuccessful mainly due to the interplay of socio-economic interests. Since operators can use free raw materials (wood from natural forests or farm clearing) and turn them into a marketable commodity in high demand, there is the need to have much respect for the sustainability of the resource. High and ever-increasing demand for charcoal, coupled with improper forest management, and poor regulation of the trade present a solemn future for forests in Africa (UNFPA, 2009). Fuelwood extraction has been cited for increasing soil erosion, reducing soil moisture content and decreasing soil fertility as nutrient leaching is increased (Angelsen and Kaimowitz, 1999). Vegetative cover and subsoil nutrients are also fast declining through the charcoal activities. These are then associated with more extensive effects including reservoir siltation, flooding, water shortages due to shifting ground water regimes (Oguntunde *et al.,* 2008) and biological impacts such as reduced faunal abundance (Ogunkunle and Oladele 2004) and biodiversity. The most important perhaps is change in species compositions as cutting influences the survival and reproduction of preferred fuel species relative to less preferred species.

Charcoal making in Asia as observed by Chomcharn (1991) was still away from the preferred development stage i.e. the realization of a sustainable and efficient system in supply of wood, processing, distribution and end use of charcoal. In many Asian countries, there existed charcoal making systems in which supply of fuelwood resources were sustainable or being created on farms. He described five resource bases in the existing charcoal production systems *viz.* the production from farm and homestead forests, mangrove forests/plantation, rubber wood, sawmill wastes and coconut shell. Various techniques were in operation and notable among them were rice husk mound, earth mound pit, mud beehive, brick beehive, sawdust mound and drum. The normal technology oriented intervention aimed at conservation of forest trees by improving quality of charcoal and efficiency of charcoal production systems had so far met with limited success. The reason as pointed out by Chomcharn (1991) was a lack of relevant and adequate field information, particularly how the existing charcoal production systems operated and their contribution both in energy and socio-economic terms.

Not including time spent during extraction and packaging, producers will often spend over two weeks vigilantly monitoring the kiln to ensure that the process of carbonization in the absence of oxygen, or pyrolysis, is properly conducted (Ribot, 1998). Extreme temperatures combined with volatile chemical compounds, including carbon monoxide and sulfur dioxide; create an extremely dangerous environment for any human, especially those without adequate safety protection. Producers are often known to spend the night within a few feet of a burning kiln to ensure that any gaps are quickly sealed.

Health-related impacts associated with woodfuels have traditionally focused on effects from their consumption. Indoor air pollution (IAP) is the primary concern given the high concentrations of particulate matter released during charcoal combustion. Smith *et al.,* (2002) documented trends in respiratory illness among disproportionate numbers of women and children as a result of IAP from woodfuel combustion throughout the developing world (Smith, 2002). However, little is known about the health impacts endured by charcoal producers during extraction and production phases (Subramanian, 2000). For example, it is known that pyrolysis, the process utilized for the production of charcoal, releases significant amounts of gaseous by-products, including carbon monoxide, sulfur dioxide and others (Bailis *et al.,* 2005; Pennise *et al.,* 2001) known to be deadly to humans in moderate concentrations through the use of dose-response studies (Muhammad *et al.*, 2005). Rural producers are known to work within close proximity to high temperature kilns that off-gas these highly toxic compounds, generating potential high risk for poisoning. In addition, use of primitive tools can potentially lead to moderate or severe injuries, which can prove fatal in rural areas that lack access to adequate medical care. Academic literature and government reports refer to the working conditions of charcoal producers as unsafe (Arnold *et al.,* 2006; World Bank, 2012); government officials and research papers alike mention these ‘hazards’ in passing. Additional indicators of social threats include widespread child labor, gender differences in education and production outcomes, extreme price variability often at the hands of merchants (Ribot, 1998), and the lack of potential for poverty alleviation in current methods of production (Fisher, 2004). The lack of regulation in the charcoal industry creates the highest risk of exploitation and safety hazards (Maes and Verbist, 2012), yet no studies have investigated in-depth the health and social risks associated with the production of this highly demanded fuel.

According to Domac *et al.,* (2008), a small scale charcoal production unit can emit quantities of particulate matter (PM), carbon monoxide (CO), nitrate oxides (NOx) and sulphate dioxide ($SO_2$), hydrogen fluoride (HF), hydrogen chlorine (HCl), formaldehyde, phenol, acetic acid, xylene and toluene. Ezzati and Kammen (2002) emphasized that charcoal contains approximately 80% of fixed carbon, 24% of volatile compounds, 4% of ash, 0.53% of nitrogen and 0.01% of sulphur. However, Ezzati and Kammen (2002) and Serenje *et al.*, (1994), on their researches on the health impacts from charcoal burning in households of developing countries, have showed that in comparison with other biomass solid fuels, primary firewood, etc., emissions of particulate matter (PM) are much lower. Pawar and Rothkar (2015) hold that awareness on the environmental and health effect particularly by the users of charcoal is very low. Although charcoal production can be considered a lucrative activity and its main product (charcoal) being an energy source reachable by about 70% of Kenya's population, there is urgent need for awareness creation (Njenga *et al.,* 2013) on the effect of this activity on present and future forest cover availability (Mwampamba, 2007). Pawar and Rothkar (2015) insist that the effects of forest cover depletion are long lasting and devastating and therefore the participation of all mankind in forest conservation is not only vital, but dire. This can only be achieved when people take informed decisions like limiting their demand on charcoal and adopting the use of energy sources like LPG, thereby by saving the forest and reducing emissions of GHGs.

Although charcoal is a major source of income for some rural and urban dwellers (Kammen and Lew, 2005) its negative consequences cannot be undermined. Burning down the forest to satisfy energy needs for household cooking and heating creates direct environmental and health issues (Atteridge, 2013). A likely environmental impact of charcoal production and use is the depletion of forest cover which in turn will lead to biodiversity loss, soil erosion, and changes in forest water table (Gichuho *et al.,* 2013). Girard (2002) stated that in places where high fuelwood and charcoal consumption and weak supply sources put strong pressure on existing trees resources (because of high population density, low income and/or severe climate conditions), deforestation and devegetation problems are still of great concern.

Fuelwood extraction has been cited for increasing soil erosion, reducing soil moisture content and decreasing soil fertility as nutrient leaching is increased (Angelsen and Kaimowitz, 1999). Vegetative cover and subsoil nutrients are also fast declining through the charcoal activities. These are then associated with more extensive effects including reservoir siltation, flooding, water shortages due to shifting ground water regimes (Oguntunde *et al.,* 2008) and biological impacts such as reduced faunal abundance (Ogunkunle and Oladele, 2004) and biodiversity.

The above review of literature reveals that there is limited information on charcoal production, utilization, quality aspects and its impact on environment. Most of the works on these aspects are reported from Africa and few works have been conducted in Asia and some states of India. However, reports on such studies are still meager from North Eastern region, including the state of Mizoram. Present investigation, therefore, is expected to fill the information gap in connection with production and utilization of wood charcoal in the state. Since charcoal production and trade is a potential source of employment and livelihood for many people in Mizoram, it needs significant attention from the policy makers and the researches for improvement, and in this direction the outcome of the present study would help the stake holders to formulate appropriate strategies for sustainable utilization of this valuable resource in the state.

## Chapter 3
## MATERIALS AND METHODS

### 3.1 Study area

The study area comprises of the whole of Mizoram state, covering all the 8 (eight) district headquarters *viz*., Aizawl, Kolasib, Serchhip, Champhai, Mamit, Lawngtlai and Siaha, and randomly selected villages representing each district to investigate the production and use pattern of charcoal.

However, to assess the quality attributes and charcoal produced and to evaluate the environmental impact of charcoal production sampling was carried out in Tualpui and Tualte village of Champhai district, Mizoram. Besides, to understand the indirect effect of charcoal production on soil, a poly pot experiment was further conducted to assess the growth and yield of selected agriculture crops in a poly house of Department of Horticulture and Medicinal and Aromatic Plants (HAMP), Mizoram University, Aizawl by collecting soil from the charcoal production and the adjoining areas in Tualpui village of Champhai district, Mizoram.

### 3.1.1 Profile of the study area:

#### 3.1.1. A Mizoram

Mizoram is a state in northeastern India with Aizawl as its capital city. Within the northeast region, it is the southernmost landlocked state, sharing borders with three states *viz.* Tripura, Assam and Manipur. The state also shares a 722 km border with the neighboring countries of Bangladesh and Myanmar.

***Demography and economy***

Mizoram population was 1,091,014, according to a 2011 census. Mizoram covers an area of approximately 21,087 square kilometers and about 91% of the state is forested. About 95% of the current population is of diverse tribal origins who settled in the state, this is the highest concentration of tribal people among all states of India. Mizoram is a highly literate agrarian economy, but suffers from slash-and-burn *jhum*, or shifting cultivation, and poor crop yields (State Agriculture Plan, Agriculture Department, Government of Mizoram, 2013). In recent years, the jhum farming practices are steadily being replaced with a significant horticulture and bamboo products industry (Directorate of Agriculture, Government of Mizoram 2013) & (Mizoram Economy IBEF, New Delhi 2010).

The state's gross state domestic product for 2012 was estimated at Rs. 6,991 crore (US$970 million) (Planning & Programme Implementation, Department Government of Mizoram 2013). About 20% of Mizoram's population lives below poverty line, with 35% rural poverty (Reserve Bank of India, Government of India, 2013). The state has about 871 kilometres of national highways, with NH-54 and NH-150 connecting it to Assam and Manipur respectively. It is also a growing transit point for trade with Myanmar and Bangladesh (IBEF India).

***Geography***

Mizoram is a landlocked state in North East India whose southern part shares 722 km long international borders with Myanmar and Bangladesh, and northern part share domestic borders with Manipur, Assam and Tripura (Planning & Programme Implementation, Department Government of Mizoram 2013). It is the fifth smallest state of India with 21,087 $km^2$ (8,142 sq mi). It extends from 21°56'N to 24°31'N, and 92°16'E to 93°26'E (Hamlet Bareh, Encyclopaedia of North-East India: Mizoram, Volume 5, ISBN 8170997925) **(Figure 3.1)**. The tropic of cancer runs through the state nearly at its middle. The maximum north-south distance is 285 km, while maximum east-west stretch is 115 km.

Mizoram is a land of rolling hills, valleys, rivers and lakes. As many as 21 major hill ranges or peaks of different heights run through the length and breadth of the state, with plains scattered here and there. The average height of the hills are about 1,000 metres (3,300 ft) gradually rise up to 1,300 metres (4,300 ft) to the east. Some areas, however, have higher ranges which go up to a height of over 2,000 metres (6,600 ft). About 76% of the state is covered by forests, 8% is fallows land, 3% is barren and considered uncultivable area, while cultivable and sown area constitutes the rest (Hydro Electric Power Policy of Mizoram, Wayback Machine, Government of Mizoram, 2010). Slash-and-burn or *jhum* cultivation, though discouraged, remains in practice in Mizoram and affects its topography (T. R. Shankar Raman, 2001) (Grogan *et al.*, 2012). The State of Forest Report 2015 states that Mizoram has the highest forest cover as a percentage of its geographical area of any Indian state, being 88.93% forest (Javadekar, *pib.nic.in*.).

***Climate***

Mizoram has a mild climate, being relatively cool in summer 20 to 29 °C (68 to 84 °F) but progressively warmer, most probably due to climate change, with summer temperatures crossing 30 degrees Celsius and winter temperatures ranging from 7 to 22 °C (45 to 72 °F). The region is influenced by monsoons, raining heavily from May to September with little rain in the dry (cold) season. The climate pattern is moist tropical to moist sub-tropical, with average state rainfall 254 cm (100 in) per annum. In the capital Aizawl, rainfall is about 215 cm (85 in) and in Lunglei, another major centre, about 350 cm (140 in) (Geological Survey of India, Government of India 2011).

Mizoram comes under the direct influence of the South-West Monsoon; as such it generally receives an adequate amount of rainfall. The rainy season (summer monsoon) generally start from the month of April, it then rains heavily from May to September and lasted till late October. The winter season i.e. November to February is generally dry, this season receives very little rainfall (Directorate of Economics & Statistics, Govt of Mizoram, 2017).

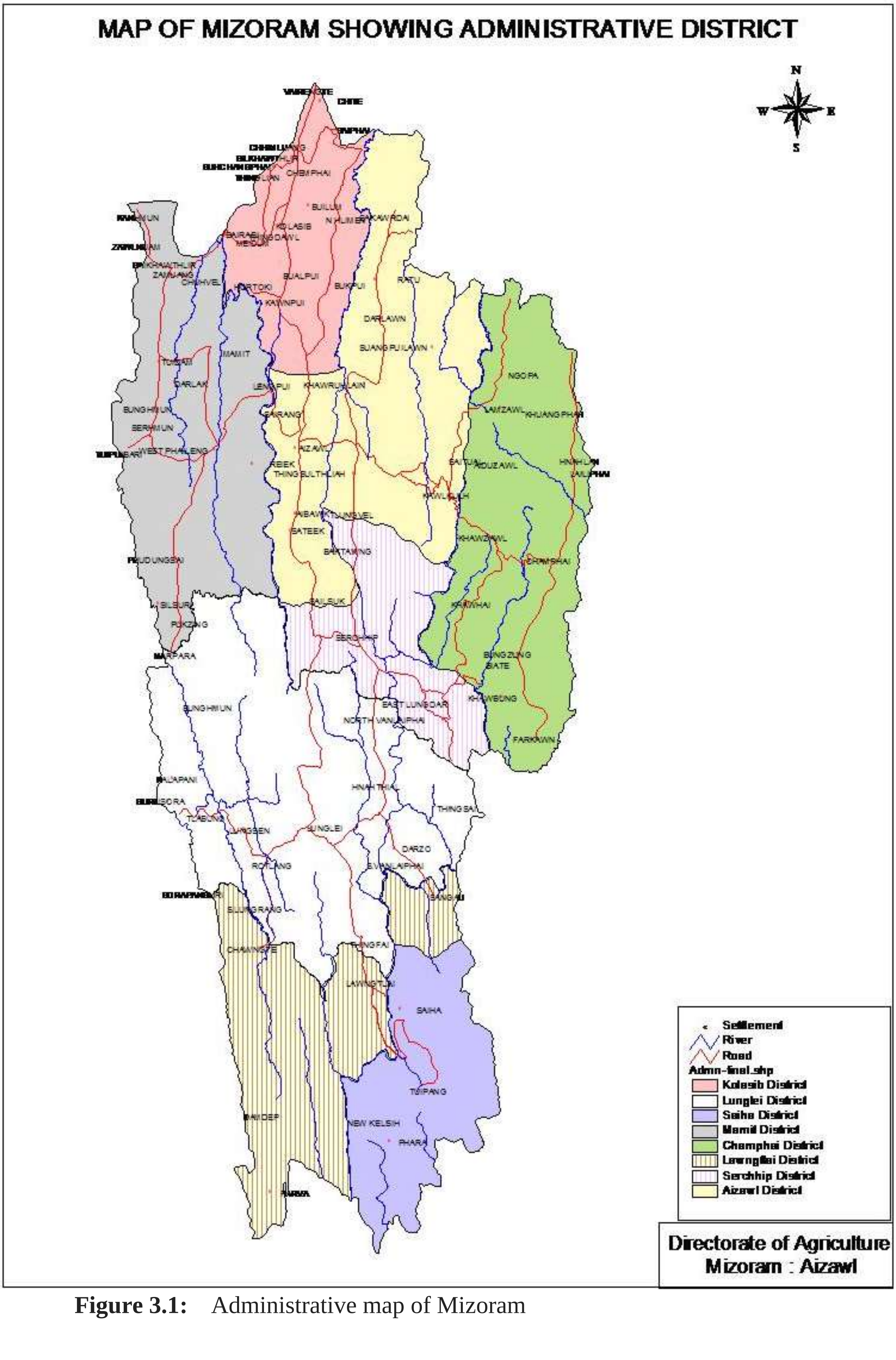



**Figure 3.1:** Administrative map of Mizoram

***Agriculture***

Around 55% to 60% of the working population of the state is annually deployed on agriculture (Directorate of Agriculture, Government of Mizoram 2013). The sector's contribution to the gross state domestic product was 30% in 1994, just 14% in 2009 due to economic growth of other sectors (Birthal, 2010).

Agriculture has traditionally been a subsistence profession in Mizoram. It is seen as a means for generate food for one's family, ignoring its potential for commerce, growth and prosperity. Rice remains the largest crop grown in Mizoram by gross value of output (Dikshit and Dikshit, 2014). Fruits have grown to become the second largest category, followed by condiments and spices (Birthal, 2010).

Before 1947, agriculture in Mizoram predominantly used to be slash-and-burn driven *Jhum* cultivation. This was discouraged by the state government, and the practice has been slowly declining (Sify News, 2012). A report of Goswami *et al*., (2012) estimates the proportion of shifting cultivation area in Mizoram to be about 30% - predominant part of which was for rice production (56% to 63% depending on the year). Despite dedicating largest amount of labour, jhum cultivated and non-jhum crop area to rice, the yields are low; Mizoram average rice yields per acre is about 70% of India's average rice yield per acre and 32% of India's best yield. Mizoram produces about 26% of rice it consumes every year, and it buys the deficit from other states of India (Directorate of Agriculture, Government of Mizoram, 2013).

The crop area used for jhum cultivation rotates in Mizoram; that is, the area slashed and burnt for a crop is abandoned for a few years and then *jhumias* return to slash and burn the same plot after a few years of non-use. The primary reasons for cyclical jhum cultivation includes, according to Goswami *et al.*, (2012) personal, economic, social and physical. Jhum cultivation practice offers low crop yields and is a threat to the biome of Mizoram; they suggest increased government institutional support, shift to higher income horticultural crops, and assured supply of affordable food staples for survival as means to further reduce jhum cultivation.

***Vegetation***

The state is divided into 12 forest divisions falling under three territorial circles. The forests of Mizoram are governed by the Mizoram (Forest) Act, 1955. Commercial utilization of the forests is prohibited but small felling is permitted for the use of *bonafide* locals to meet their needs (State of Forest Report, 2006). Mizoram falls under temperate zone having sub-tropical climatic condition with short and dry winter.

The sub-tropical humid climate favours luxuriant growth of vegetation and forests. The forests are divided into Protected Areas, reserve forests and unclassified forest. According to State of Forest Report, open forest occupies 61.18%, scrub 0.01%, moderately dense 28.87%, very dense 0.64% and non-forest 9.3% to the total geographical area of the state. Area under recorded Forest is 16,717 Km² (ISFR 2011). The reserved–forest covers 6465 Km² and the protected forest covers 941 Km² (Anon., 2008a). According to Champion and Seth (1968), the forest of Mizoram has been classified into three types, mainly based on the altitudinal ranges:–

(1) Tropical wet-evergreen forests (up to 900 m)

(2) Tropical semi-evergreen forests (900-1500 m)

(3) Montane Sub-tropical Pine (above 1500m)

The State has a Forest cover of 91% and the forests in Mizoram are classified as tropical wet evergreen, tropical moist deciduous and sub-tropical pine forests (SFSI Report, 2013). Based on past studies as well as from the field observations, Singh *et al.*, (2002) described the forest type of the State based mainly on altitude, rainfall and dominant species composition. The classification is as follows:-

1. Tropical Wet Evergreen Forest
2. Montane sub-tropical Forest
3. Temperate Forests
4. Bamboo Forests
5. Quercus Forests
6. Jhumland.

**1. Tropical wet evergreen and semi-evergreen forests:**

These forests usually occur below an altitude of 900m and form one of the major forest types of the State with rich species diversity. Patches of these forests can be seen usually on the steep slopes, rocky and steady river banks and areas not suitable for shifting cultivation. The exact distinction between the evergreen and semi-evergreen forests is difficult as they occur in the areas of similar characteristics where rainfall averages between 2,000-2,500mm annually and temperature varies between 20 $^{o}$C to 22 $^{o}$C. Tropical wet evergreen forests are met usually in southern and western part of Mizoram, while semi-evergreen forests occur in northern, north-western and central part of the State.

The tropical wet evergreen forests exhibit clear zonation or canopies consisting of an admixture of numerous species with dense and impenetrable herbaceous undergrowth. Most of the species of the top canopy are evergreen trees with tall boles. Cauliflory is rather common. The middle and lower canopies are dense, evergreen and diverse. Epiphytes and parasites are few. Tree ferns, aroides, palms, ferns, orchids, bryophytes and lichens are fairly common. Lianas are frequent and conspicious, sedges and grasses are common in humid places or along the banks of rivers and rivulets. Species of *Musa* are also common along the streams on hilly slopes.

In exposed and drier areas, having a thin of soil, deciduous elements along with some evergreen trees are found. Sometimes these are grouped as distinct type, referred as tropical moist deciduous forests. The distinction between the tropical evergreen forests and tropical moist deciduous forests is difficult as they are found in the small hill ranges.

**2. Montane sub-tropical forests:**

These forests are usually found between 900 and 1,500 m altitude in the eastern fringes bordering Chin Hills of Myanmar, and places which are cooler and have less precipitation. Sub-tropical vegetation shows mixed pine forests. The common species of these forests are *Castanopsis purpurella, Duabanga grandiflora,* *Myristica spp., Phoebe goalparensis, Pinus kesiya, Podocarpus neriifolia, Prunus cerasoides, Quercus acutissima, Q. semiserrata, Schima wallichii, etc.*

**3. Temperate forests:**

These forests usually occur above the elevation of 1,600m in areas like Lengteng, Naunuarzo, Pharpak, Thaltlang, Phawngpui reserve forests and display impenetrable virgin primary forests. These forests are not typical temperate forests as found elsewhere in eastern Himalaya. The predominant arboreal elements in the forests are *Pinus kesiya, Actinodaphne microptera, Betula alnoides, Exbucklandia populnea, Elaeocarpus serratus, Dillenia pentagya, Michelia doltsopa, M. champaca, Garcinia anomala, Schisandra neglecta, Photinia intergrifolia, Litsea salicifolia, Myrica esculenta, Lithocarpus dealbata, Rhododendron arboreum,* etc.

**4. Bamboo forests:**

Bamboos usually grow as an under-storey to the tree species in tropical evergreen and sub-tropical mixed-deciduous forests, whereas *Melocanna baccifera* forms dense or pure forests in certain areas in the State. Large tracts of bamboos are seen throughout Mizoram but their distribution is somewhat restricted to about 1,600m and below. They occur mostly between 40m and 1,520m in tropical and sub-tropical areas. Few species occur in temperature areas in Blue Mountain and Mount Chalfilh. It appears that bamboos have resulted from jhumming system of cultivation (Deb and Dutta, 1987). For practicing jhum cultivation the forests are burnt and tree species are destroyed but the bamboo rhizomes throw out new culms as soon as favourable temperature and seasonal monsoon arrive. Therefore, in abandoned jhumland they are the first colonizer and grow rapidly. Some important associates found growing along with bamboos are *Emblica officinalis, Litsea monopetala, Pterospermum acerifolium, Terminalia myriocarpa, Caryota mitis, Artocartus chama, Duabanga grandiflora, Albizia procera, Gmelina arborea, Syzygium* species (Singh *et al*., 2002).

**5. Quercus forests:**

These forests are mostly found intermingled in sub-tropical and temperate areas. Pure patches or predominate *Quercus griffithiana* is present near Champhai-Baite hill ranges and its distribution is restricted to other small areas in the eastern part of Mizoram. *Lithocarpus dealbatus* is other main species (Singh *et al*., 2002).

**6. Jhumland:**

Jhumlands are very common in Mizoram. They are classified variously as current jhumland, old jhumland and abandoned jhumland. Jhumlands are more prevalent in eastern Mizoram where extensive and intensive jhumming is practiced. Similarly, the areas in western side in Lunglei district towards Bangladesh have also Jhumlands.

### 3.1.1.B Tualpui and Tualte villages

Champhai district is located at the east most of Mizoram and the study sites were located around 40kms apart from each other, whereas Tualpui site (kiln method of production) (23º 37’37.1”N and 93º 13’083” E at an altitude of 1345m above sea level) is situated at 8kms towards Rabung road from Tualpui village, Champhai District of Mizoram **(Figure 3.2)**. Tualte study site (pit method of production) is situated at about 5kms from the Tualte village itself, located at 23º 23’36.8” N and 93º 12’48.7” E **(Figure 3.3)**. However, both the sites are having similar meteorological condition of annual rainfall of 1898mm; mean annual temperature of maximum and minimum of 27.5 ºC and 9 ºC, relative humidity of maximum and minimum of 96.73% and 77.06% during 2016-2017. The soils of the study area are dominated by Entisol (DAO, Champhai, 2017). The economies of these villages are mainly on agricultural hill farming where slash and burn (jhum) is the main practices. In view of the fact that these villages have access to LPG and electrification, these villages have dense forest resources in their surroundings, which endow with wood stands, charcoal production become an important source of income in conjunction to farming. Hence, most of the farmlands are utilized for charcoal production and there are many patches of kiln and pit method of production in these areas. Thus, these two sites were strategically selected for conducting the experiment.

### 3.1.1.C Mizoram University

The experimental site was in the department of HAMP, Mizoram University Campus, Aizawl which is situated about 15 km west of the state capital Aizawl, just below Tanhril village. The study area lies in between 230 45’25’’ and 230 43’ 37” N latitudes and 920 38’ 39” and 920 40’ 23” E longitudes, with the elevation ranging from 300 m to 880 m asl. The area is characterised by a series of undulating slopes with the Western spur fallings under steep slope of the bank of Setlak River. The climate is humid and tropical, characterized by a short winter and long summer with heavy rainfall (2,100 mm). The temperature did not fluctuate much throughout the year, and ranged from 12 °C to 36 °C.

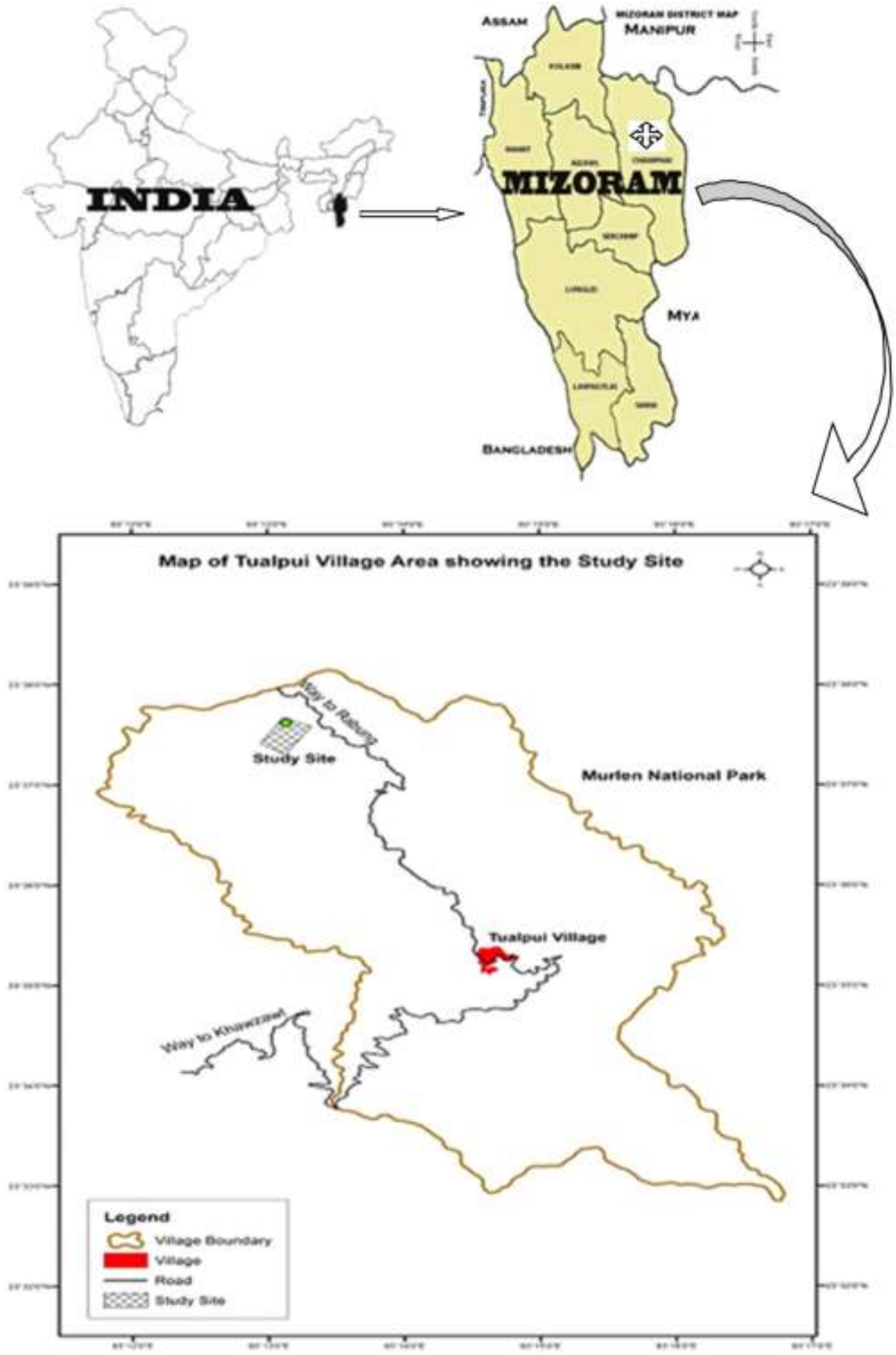
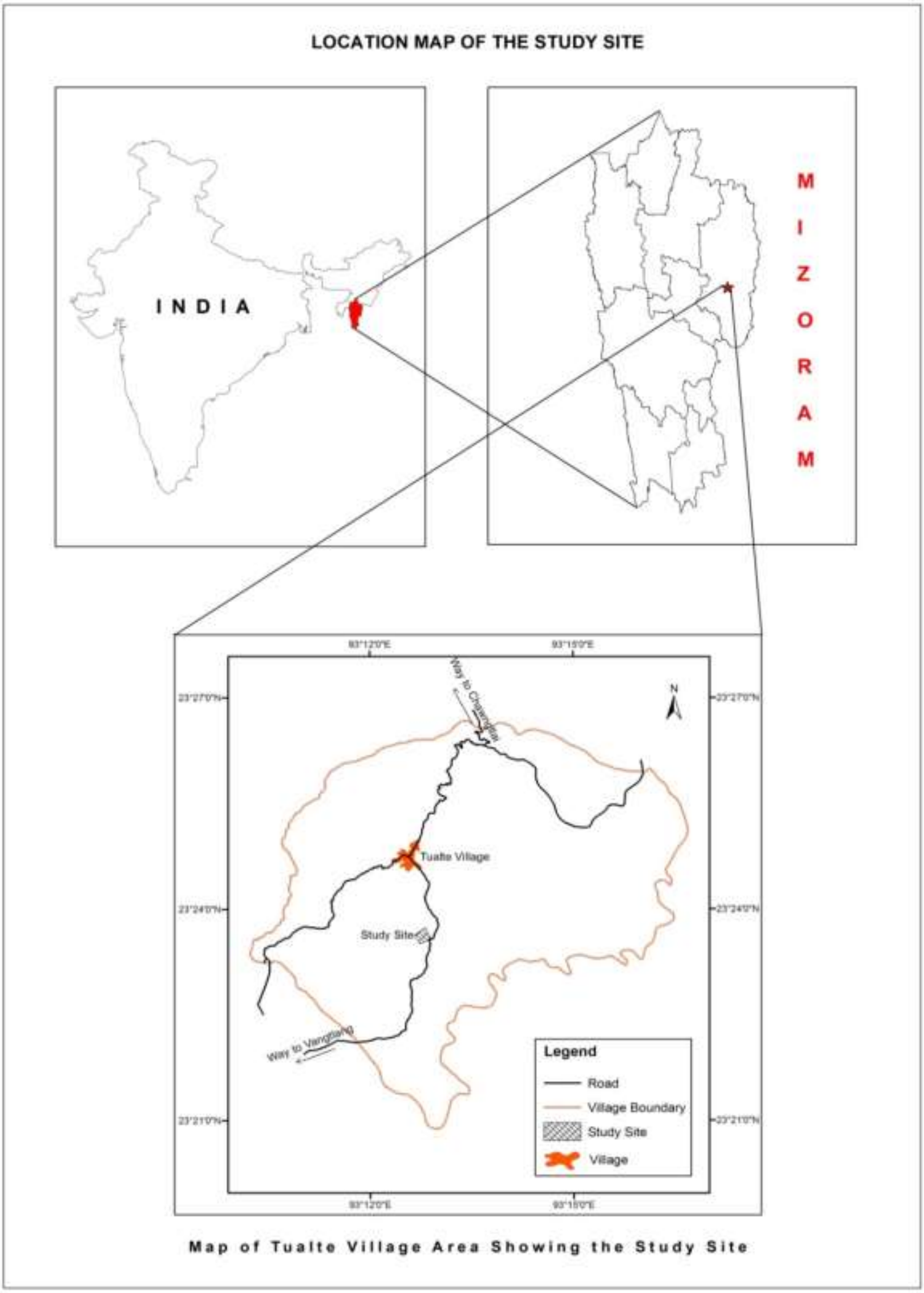



**Figure 3.2:** Map showing study site of Tualpui village, Champhai district.




*(Courtesy of MIRSAC, Directorate of Science and Technology, Mizoram)*

**Figure 3.3:** Map showing study site of Tualte village, Champhai district

## 3.2 Methodology

### 3.2.1 Charcoal Production and Utilization

To study production and use pattern of charcoal, traders, wholesalers, major retailers and end users of wood charcoal in eight towns of district headquarters were identified and data on the charcoal industry as well as trade channel were collected by questionnaire of both close ended and open ended type. The components of the study were undertaken in sequence: first, the household survey of energy consumption; second the charcoal supply chain analysis; and finally the charcoal production survey. In this way, it was possible to follow the charcoal industry upstream from consumers, along the market chain and back to the producers.

The study was carried out during 2013 to 2016 throughout the state of Mizoram in which all the districts towns and selected villages are covered by conducting random questionnaire to selected respondents. The districts of Aizawl, Champhai and Serchhip were purposefully selected as these are the main charcoal dealing areas. Participant observations along the supply chain from the resource base up to the consumer in each towns and selected villages of the districts were interviewed, complemented by the use of questionnaires for all the stakeholders involved in the supply chain. Tools utilized in the field study were: Questionnaire survey for producers, transporters, middlemen, wholesalers /retailers, focus group discussions, personal interviews with key informants, entrepreneurs, intermediaries, service providers, government officials, and non-governmental organizations.

An extensive field survey was carried out in the state for a year. During the survey, observation was made on a number of variables. The primary data was obtained through semi-structured questionnaires and oral interviews with those respondents who have in depth knowledge and those involve in charcoal industry. A total of 480 questionnaires were distributed to all the sampled areas under study, comprising of separate questionnaire for each participants. Stratified sampling method was used in order to ensure comparability between each district capital and its surrounding rural areas. The study area was stratified into district wise, divided into two main components such as district capital area (trading and end use) and rural area (mainly production); 3 localities randomly selected from each 8 capitals and according to the extent of charcoal trade, 3 or more villages were selected from each districts. The layout of questionnaire administered in each area is presented in **Table 3.1**. Since the urban areas have higher population density and therefore more questionnaires were administered in each capital; while lesser questionnaires were administered in the respective villages of each district. However, depends on the magnitude of production and trade within the district, the figure of respondents were essentially varies. Survey was conducted to study the following components:

**Table 3.1:** Layout of sampling pattern of questionnaire

| Capital/Town Area | | | Village/Rural Area | |
|---|---|---|---|---|
| No of district capital | 8 | | No of district | 8 |
| No of stratified localities | 3 each = 24 localities | | No of stratified villages | 3 each = 24 total villages |
| Sample size (respondents) | 10 each | | Sample size (respondents) | 10 each |
| Total | 240 | | Total | 240 |

| | |
|---|---|
| **Grand total** | **480** |

### 3.2.1.A *Charcoal production*

The data for this study was obtained from both primary and secondary sources. The primary data was obtained through questionnaire survey and structured interview with consumers, retailers/ stockist, middlemen and transporters, environment & forest officials, community heads, entrepreneurs, cooperative societies and some NGOs. The questionnaire consisted of open and close ended questions and was administered to respondents sampled randomly from each stratum in the area. Field observation was conducted in the study site with producers where the charcoal production takes place. The purpose of observation is to check the availability, quantity, distribution, location and type of plant species in study area. The information collected from the questionnaire include source of wood charcoal, amount of supply, frequency, identification of middlemen and stockist/wholesaler quantity of wood charcoal consumed per household or business center. This enabled the study to establish the extent to which charcoal producers understand and adopt sustainable practices of charcoal burning. Data relatives to the quantity of charcoal produced were collected in the forest checkpoints. After identifying the supply region, producers were selected randomly from each villages and interviewed, since Champhai district has the largest producers in village wise as per the primary data, consequently the largest numbers of producers were interviewed from it and some from the rest of districts.

### 3.2.1.B *Transporter/ Middlemen/ Supplier*

Transporters were interviewed both in the production areas as well as in the markets. The transporters and middlemen both from the respective producing villages and those regular middlemen who are operating from the capital and district headquarters are identified and administered with the prepared questionnaires.

### 3.2.1.C *Retailers/ Stockists*

Vendors both retailers and wholesalers were located in the various urban area of each identified districts and they are interviewed. The numbers of these dealers depend on the demand of charcoal within the area they are operating. Accordingly, the sample size is varied with each identified location. A random survey regarding charcoal price were conducted mainly through the collection and selling centers. A further survey of supply chain and sources of charcoal were also conducted.

### 3.2.1.D *Households and Consumers*

Interviews to consumers at household level were taken in randomly selected houses and other end users in markets. A limited number of stratified informants were randomly interviewed and questionnaires were used to administer their responses.

Data used in this study was obtained from two main sources: primary and secondary. The primary sources included field survey, questionnaire, (Rapid

Appraisal and Sample Survey) and personal observation. The secondary data was also obtained from available documents, reports, journals, official statistical books and literatures. Thus these serve very good complements to the primary data.

Four approaches were employed in the study:

- Exploratory/Familiarization Visit and Reconnaissance survey
- Socio-economic survey
- Informal personal interview
- Focus Group Discussion

**1. Exploratory and Reconnaissance Survey**

This was done during the preparatory stage of the study: a periodic visit was undertaken to the study area to familiarize with the key informants and respondents to hold discussion with them. The survey had three main objectives:

- To identify possible households/wood charcoal dealer from which random samples were to be taken for actual survey.
- To establish rapport/contact with some charcoal dealers in some of the chosen areas.
- To rapidly appraise some of the wood charcoal dealer in the area.

**2. Socio-economic Survey**

A structured questionnaire was used to obtain socio-economic characteristics of wood charcoal dealers: A cross section of producers, traders and users from each of the selected community who availed themselves were interviewed. In all, producers, transporters/ distributors, traders/ middlemen, stockist/retailers and household users of wood charcoal were interviewed. Questions asked bordered on demographic features of households, household involvement in raw material collection, charcoal production, trade and decision making on consumption. Market survey conducted focused on the rate of charcoal, amount retailed, supply and demand sources. Other information that the questionnaire collected included the pattern of wood charcoal use and supply, channel of distribution, policy and institutional arrangements that affect the business and the general impact on the livelihood of the inhabitants of the study area. The questionnaire was pre-tested and modified. A copy of the survey instrument (questionnaire) is provided in Appendices.

**3. Informal personal interview**

Questionnaire interview was followed by informal interview, which was used to collect additional information, which could not be obtained by the formal questionnaire method. Personal interview and discussions were held with the wood vinegar manufacturers, which disposing off their charcoal to users, village/community elders, cooperative societies and other entrepreneurs. The study also used Key Informant Interviews to beef up information collected through the personal interviews.

**4. Focus group discussion**

The focus group discussion involved community leaders, elders, and authorities in the area. This was an open discussion encompassing exchange of views and comments. The questionnaires utilized for members of village communities as well as those used for government authorities are shown in the appendices.

**Sample determination and sample size**

The survey area is made up of 8 (eight) district's capitals and villages clustered around other smaller settlements in each districts. The main identified wood charcoal industry are Aizawl, Champhai and Serchhip districts, at the same time charcoal production is mainly from Champhai district. Proportionate sample size was chosen from these districts. The basis for the choice of these study sites included:

- Those districts that produce wood charcoal for sale.
- Their nearness to the forest reserves
- Regions which are rich in hardwood species
- Those communities which are practicing jhum cultivation.

## 3.3 Data Analysis

The data collected was validated to get the relevant data from the study. The data collected from the study was analyzed quantitatively and qualitatively. The validated data was coded for easy classification in order to facilitate tabulation. The tabulated data was then analyzed quantitatively by calculating various percentages wherever possible. To analyze statistical data, the study used Microsoft Excel, Statistical Package for Social Science (SPSS), ANOVA, Duncan Multiple Range

Test, OPSTAT, etc. Data was summarized in the form of frequency distribution tables, graphs, bar charts, pie charts as well as statistical measure of central tendency. These tools enabled the study to analyse the data considering the variables measured and objectives set. The choice of the analytical tool was made based on the statement of the problem, objectives and the central theme (hypothesis) of study.

### 3.3.1 Assessment of charcoal quality and production efficiency

Data on the species used, source, harvesting pattern, preprocessing, method of production, storage, post production handling, transportation and source of disposal were collected from identified traditional producers through pre-structured questionnaires prepared for the purpose. Tagged samples of the species used traditionally by the producers are converted to charcoal and their quality attributes are estimated. Similarly, the wood samples of same species are collected from the same area and the similar qualities are also tested in the laboratory for comparing with their carbonized state.

**Sampling for laboratory experiments**

**Species preference and Wood sampling**

A survey was made to identify the commonly used tree species for charcoal production by the rural people of Mizoram. For this surveys were made to various charcoal producing localities of the state and interviewed more than 50 numbers of local charcoal producers. To know about the preferences given on these tree species for charcoal production and also about their availability in the state, key informants from various locations of charcoal producers who were having 10 to 15 years of experiences in charcoal production were selected. They were asked about the level of preferences for these tree species for charcoal production and also about their availability in the state, especially in the charcoal producing areas.

Results from the information collected through the personal interview of the charcoal producers about the indigenous tree species commonly used for charcoal production and preference given on them for charcoal production are listed and tabulated.

For each of the tree species, wood samples were collected from four different randomly selected trees of the age group 10-15 years and grown in their natural habitats from Champhai district of Mizoram during 2014. Size of the wood samples collected were 10 cm in length with diameter classes ranging from 10-15 cm, 15-20 cm and 20-25 cm outside the bark. Freshly cut wood samples of each of the tree species were put in polythene bags and sealed to avoid loss of moisture from it. They were labeled and subjected to the laboratory for experimental works.

### 3.3.2 Physico-chemical properties of wood sample

**Analytical methods**

Dry wood samples were first ground to fine powder form. This was then passed through a 40-mesh (0.4 mm) sieve and the resultant particles of size less than 0.4 mm were taken for analysis.

The wood samples thus obtained were further prepared according to TAPPI method (T 264 om-88). This includes i) fractionation of very fine materials that may clog fine filters or pass through coarse filters producing erroneous results, ii) extraction with ethanol-benzene except where the extraction process and subsequent washing could interfere with certain chemical analysis.

**1. Determination of moisture content**

Moisture content (MC) of the wood samples was determined according to the TAPPI method (T 258 om-89). For this, a 10g of sample was weighed immediately after sampling and then air-dried. This air-dried sample was taken in an aluminum box and kept in an oven at 105 ± 3 °C until constant weight was attained. The difference of green weight and the oven dry weight was considered as moisture content.

$$MC\ \% = \left[\frac{Wc - Wd}{Wc}\right] X\ 100$$

where,

Wc = Air dried weight of wood sample (10g)

Dc = Oven dried weight of wood sample at 105 °C (≠ 0.0005g difference)

MC = Moisture content.

For each sample, the estimation was done in triplicate and the mean value was reported.

**2. Determination of wood density**

Air-dry density and oven-dry density were determined according to TAPPI method (T 258 om-89). Air-dry density was obtained by dividing the air-dry weight by air-dry volume while oven-dry density was obtained by dividing oven dry weight by oven-dry volume. Volume of the wood samples was determined by water displacement method.

$$\rho = \frac{m}{v}$$

where,

$\rho$ = Density

m = mass of wood (g)

v = volume ($cm^3$)

For each sample, the estimation was done in triplicate and the mean value was reported.

**3. Determination of ash content**

Ash content of wood samples was determined according to TAPPI method (T 211 om-85). At first, the silica crucible was heated in a muffle furnace at 575 ±25 °C for 15 min., placed in desiccators for 45 min. and weighed to nearest 0.1 mg. Test sample was then placed in the crucible and weighed accurately. It was then kept in a muffle furnace. The furnace temperature was gradually raised to 575±25 °C so that the material was carbonized without flaming. The sample was allowed to stay at that temperature for 3hrs or longer to burn away all the carbon, completion of which was indicated by absence of black particles. The crucible was then taken out of the furnace, cooled in a desiccators and weighed to the nearest 0.1 mg.

$$Ash\ \% = \frac{Weight\ of\ ash}{Weight\ of\ sample}\ X\ 100$$

For each of the wood samples, the test was conducted thrice and the mean value was reported.

**4. Carbon content**

Carbon content is estimated as prescribed by IPCC (2006).

$$Carbon\ \% = 100 - (Ash\% + 53.28)$$

**5. Determination of calorific value**

The calorific values of the wood samples were determined with the help of a Bomb Calorimeter (Model: 5E -1 AC/ML) as per the method recommended by the Indian Standard Institution (IS: 1359-1955) (Bureau of Indian Standards, 1960). The protocol for determination of calorific value was as follows:

**Charcoal sampling for laboratory experiments**

The most important properties of charcoal are those that determine its quality. *Charcoal quality* is defined in terms of moisture content, volatile matter, calorific/ heat value, fixed carbon and ash. These are termed as chemical properties. Physical properties relate to charcoal's bulk density and resistance to fracture (friability).

The testing methods for by-products are derived from the American Society for Testing Materials (ASTM). Most of the present methods are based on ASTM methods for coal and coke (D271-48; D-346-35). Various modifications of these and other methods are also used. However, physical properties of the produced charcoal were determined using the American Standard Testing Method (ASTM D1102-56). The method described here is intended specifically for charcoal. It employs equipment found in most laboratories, and is adapted to routine analyses of a large number of samples. Since this method differs from ASTM methods D-271-48 and D-346-35 in several details, data for duplicate determinations on samples were analyzed statistically. Since the data revealed that the production of charcoal is maximum in Champhai district, the materials were of specific samples of charcoal obtained from the product of one batch of a single kiln from Tualpui village, Champhai district.

**Field level carbonization of charcoal**

The field level carbonization experiments with 10 tree species included among the 24 tree species of the present study were carried out in kiln method. The size of the kiln was of medium size which is the most common size of kiln used by the charcoal producers in Mizoram. The 10 major tree species according to preference wise of varying girth were collected from the felled wood lot and cross-cut into logs of 1- 1.5m long. The logs were air dried and somewhat green, as preferred by the producers. The woods were hauled inside the kiln in an upright position and stacked in manner of species wise. To facilitate ignition, a kindling was placed at the ignition point and the fire was started. When the fire had caught after sometime, the opening was covered by earth-turf leaving a small hole opening for entering air. Subsidence of combustion of the kindling on the kiln top (chimney) signaled completion of combustion. The charcoals were ready for collection after leaving in this state for 1 week. Then, the wood charcoals in species wise were carefully collected and packed in a separate container and ready for analysis.

### 3.3.3 Physico-chemical properties of charcoal

**Physical properties**

The moisture content, density, ash content, volatile matter and fixed carbon content of the charcoal thus produced were determined by using the same standard methods as used in the case of charcoal samples produced in the laboratory-scale carbonizer.

The following quality parameters of the selected samples were analyzed:

**1. Determination of Bulk density of charcoal fines**

This test indicates the weight of the charcoal fines, per unit of volume, and is important for shipment calculations. For this, the charcoal sample as received from the plant or storage will be poured a little at a time into a 100 ml calibrated cylinder. After each addition the cylinder is tapped vigorously on a wooden board until the volume is constant. When the 100 ml calibration mark has been reached tapping is stopped and weighed the charcoal fines. The weight obtained multiplied by 10 gives the bulk density per litre (FAO, 1985).

$$\rho = \frac{m}{v}$$

where,

ρ = Density

m = mass of charcoal fines (g)

v = volume of cylinder ($cm^3$)

For each sample, the test was conducted thrice and the mean value was reported.

**2. Friability test**

This test measures the case with which the charcoal fractures into smaller pieces, when subjected to repeated handling and, thus, indicates the extent to which pieces will break up during transport, or during descent in end uses. For this a known quantities of charcoal were packed in gunny bags and were subjected to transport from the place of production site to a predetermined distance. The figure in % indicates the reduction in size suffered during the test. Therefore, the lower the % figure, the better the charcoal (FAO, 1985).

$$Friability\ (\%) = \frac{W1 - W2}{W1} X\ 100$$

where,

$W_1$ = weight of charcoal packed in bag before transportation and handling

$W_2$ = weight of charcoal with bag at destination minus charcoal fines

For each species wise charcoal bag, the estimation was done in triplicate and the mean value was reported.

**Chemical properties**

Moisture, ash and volatile matter contents of charcoal samples were determined according to the method ASTM D 3173, D3174, D3175 (ASTM 1988a, b, c).

**1. Determination of moisture**

Moisture content of charcoal samples were determined first by weighing a porcelain crucible preheated in a muffle furnace at 750 °C and then approximately 1g of the ground sample was placed in it. The crucible was then kept in an oven at 105 °C till constant weight was attained. Dried charcoal sample was then cooled in a desiccators for 1h and weighed.

$$MC\ \% = \left[\frac{Wc - Dc}{Dc}\right] X\ 100$$

where,

Wc = Air dried weight of charcoal

Dc = Oven dried weight of charcoal at 105 °C (2hrs ≠ 0.0005g difference)

MC = Moisture content.

Difference in weight divided by the air-dry weight gives the moisture content.

For each sample, the estimation was done in triplicate and the mean value was reported.

**2. Volatile matter**

For determination of volatile matter, a muffle furnace was heated to 950 ºC. A crucible containing the sample was placed first for 2 min on the outer edge of the furnace keeping the furnace door open and then for 3min on the edge of the furnace and finally the crucible was placed in the rear of the furnace for 6min with the muffle door closed. Sample was then cooled by placing in a desiccators for 1h and then weighed. Difference in the initial weight and final weight divided by the initial weight gave the volatile matter content. Fixed carbon was calculated by difference.

$$VM\ \% = \left[\frac{(W1 - W2)}{W1}\right] X\ 100$$

Where,

$W_1$ = initial weight

$W_2$ = final weight

VM = Volatile matter

For each sample, the estimation was done in triplicate and the mean value was reported.

**3. Ash content of charcoal**

For determination of ash content, a crucible with sample was put in a muffle furnace at 750 ºC for 6h till weight loss is ≠ 0.0005g. It was then cooled in desiccators for 1h and weighed. The weight of residue divided by the initial weight gave the ash content.

$$Ash\ \% = \frac{W1}{W2}\ X\ 100$$

Where,

$W_1$ = Ash residue weight

$W_2$ = initial weight (oven dried at 105 ºC)

For each sample, the estimation was done in triplicate and the mean value was reported.

**4. Percentage Fixed Carbon of the Charcoal Samples (PFC)**

The percentage fixed carbon, PFC was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) from 100. The carbon content is usually estimated as a "difference", i.e. all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the percentage of pure or fixed carbon (FAO, 1985). This was determined using,

$$\% FC = 100 - (\%VM + \% AC)$$

Where,

%VM = % Volatile matter

% AC = % Ash content

% FC = % Fixed carbon

For each sample, the estimation was done in triplicate and the mean value was reported.

**5. Determination of calorific value**

The calorific values of the wood samples were determined with the help of a Bomb Calorimeter as per the method recommended by the Indian Standard Institution (IS: 1359-1955) (Bureau of Indian Standards, 1960). The protocol for determination of calorific value for charcoal is same as the method followed in wood sample analysis.

For each sample, the estimation was done in triplicate and the mean value was reported.

**Conversion Efficiency of Production Method**

The efficiency of a kiln is defined as the mass of charcoal that a producer obtains from a kiln expressed as percentage of the mass of wood the producer initially put into the kiln. The conversion efficiency includes even the charcoal fines (rejects) that may not be packaged for sale due to their small size. The efficiency can be calculated on fresh/air or oven dry basis, however, the trial was conducted on green basis as follows, (FAO, 1985):

$$Ec = \frac{Mc}{Mw} X\ 100$$

where,

$E_c$ = Conversion Efficiency

$M_w$ = Mass of wood put into the kiln

$M_c$ = Mass of charcoal produced

Both the methods, such as pit and kiln method were experimented for their conversion efficiency. The mass of wood in green weight were measured before putting into stack, then after carbonization, the weight of yield charcoal were measured and the ratio of efficiency was calculated as such. The experiments were conducted separately for both the methods for comparison.

For the majority of data collected, contingency tables ANOVA tests were performed in R statistical package and Pearson's correlation were also performed. An alpha level of significance of 0.05 and 0.01 was used for all tests.

### 3.4 Environmental aspect of charcoal production

All the activities and components in the charcoal production and use systems with potential impacts on environment have been described. Following the development of impact assessment sheets for each of these, the significance of these activities and components was qualitatively assessed and presented in figures and tables. As a result of this assessment the effects of some of these activities and components were excluded from further analysis while others were selected for an in depth assessment. There are seven activities selected for analysis of ecological effects, six belonging to the "charcoal production stage" and one belonging to the "charcoal use stage". Three activities were selected for the assessment of the health effects. In the case of assessment of economic effects, it turned out that the breakdown of the three major stages in the charcoal production system was too detailed. Therefore, aggregated assessments of the effects were used with respect to employment, income/expenditure and linkages to other economic activities under three titles: charcoal production, transportation, marketing and use. Pre-determined sample sizes were difficult to obtain given the informal nature of production and lack of available information on producer demographics. Using a snowball method, where subsequent respondents referred, surveys were conducted along the roadside of jhumlands as most charcoal production occurs along major jhumlands. The districts selected for this study were done so as a result of information gathered from stakeholder interviews; large-scale charcoal production is most prevalent within these locations.

### 3.4.1 Impact on soil properties

Investigation of soil quality is one of the important factors for assessment of effect on environment by human activities. Therefore, impact of charcoal production on soil physico-chemical in comparison with soil properties of adjacent forest area were further deliberated to reveal the significance on environment. For this purpose, two sites of charcoal production were selected after intensive survey and recognition of charcoal production area *viz:* Tualpui and Tualte of Champhai district; where one site is of kiln method and another is pit method, respectively of the villages.

The composite soil samples from both the sites were collected from the depth of 0-15cm from 10 different sites of charcoal production and adjacent forest, followed by the removal of all unwanted materials. Each sample were kept and packed in a separate container and marked separately. The soil samples were air dried and sieved through a 2mm mesh and were subjected to laboratory for physical and chemical analysis.

**Physical properties**

**Soil Bulk Density**

Bulk density is the ratio of the mass of dry soil to its volume. Separate soil core samples were taken with sharp-edged steel cylinder forced manually into the soil for bulk density determination. Bulk density can be determined after drying the core samples in an oven at 105 ± 2 °C for 24hrs and calculated as:

$$Bulk\ Density = \frac{W2 - W1}{V}$$

Where, $W_2$ and $W_1$ are weights of moist and oven dry soils in grams, respectively and $V = \pi r^2 h$, is the volume of the cylindrical core ($cm^3$). Where, *r* is inside radius of cylinder (cm) and *h* is height of cylinder (cm).

**Water holding capacity (WHC)**

WHC was determined by the method of Emmanuel *et al.,* (2010) using keen boxes. The crushed soil samples are oven dried at 105 ± 2 °C for this experiment. Filter papers are kept inside the keen boxes to cover the perforated bottom of the box and measured the weight ($W_1$), the oven dried soil samples are then transferred in the keen boxes and weighed ($W_2$). The soils are saturated with water and kept for overnight, then, the next day the box is whipped and recorded the weight ($W_3$). The WHC was calculated as:

$$WHC\ (\%) = \frac{(W3 - W2)}{(W2 - W1)} \times 100$$

**Soil texture**

Soil texture was determined by hydrometer method (Piper, 2005). The textural classification according to the United States Department of Agriculture (USDA) was followed to give the nomenclature or textural class.

**Chemical properties**

**Soil pH** was measured by using a combined glass electrode in suspension pH meter of soil and water ratio 1:2.5.

**Electrical conductivity (EC)** was measured in soil to water ratio of 1:5 by using electrical conductivity meter (Deluxe conductivity meter 601).

**Available phosphorus (P)** was determined by Bray and Kurtz P (1945).

**Carbon and Nitrogen content** were determined by using CHNS/O Elemental Analyzer with auto-sampler and TCD detector –Euro Vector, Model: EuroEA3000 at Central Instrumentation Laboratory, Mizoram University, Aizawl.

**Exchangeable K, Ca, Mg and Na** was extracted with 1N ammonium acetate ($NH_4OA_c$) (pH 7.0) and determined by using the Microwave plasma atomic emission spectrophotometer (MPAES), Agilent's 4200 MP-AES at Central Instrumentation Laboratory, Mizoram University, Aizawl.

For the determination of **exchangeable acidity and exchangeable aluminium**, extraction was carried out with 1 N KCl solution followed by the addition of phenolphthalein indicator and titrated with 0.1 N NaOH solutions to the permanent pink colour. The volume of NaOH used was recorded for calculating the exchangeable acidity as described by Robertson *et al.*, (1999).

**Cation exchange capacity (CEC)** was determined by summing exchangeable cations to provide a measure of cation exchange capacity (CEC) as described by Gillman (1979).

The results of the laboratory analysis were thereafter analyzed with ANOVA-two factor analysis and Pearson's correlation in order to assess the significance difference in soil properties between soils at charcoal production and adjacent sites.

### 3.4.2 Effect of charcoal production soil on growth and yield of selected agriculture crops

In order to assess the effect of charcoal production on soil; growth and yield parameters of selected agriculture crops were studied under poly house in the Department of HAMP, Mizoram University, Aizawl.

Soils from different sites such as charcoal production site, adjacent forest soil and jhumland were collected from the study area of Tualpui village where there is a typical charcoal production by traditional kiln method. The collected soils were transported to the experimental site and filled in polypots of size 9.5" X 15.5" and labeling was done. The selected agricultural crops such as Tomato (*Lycopersicon esculentum* var. Arka Rakshak F1 hybrid) and Bush beans (*Phaseolus vulgaris*) were grown in these pots, thus, making a design of two sets of experiment.

**Growth parameters**

The plants were observed and the growth parameters such as plant height, number of branches, number of leaves, number of branches, leave area and total biomass of each treatment were measured.

**Yield parameters**

The yields of both crops were measured at the recommended harvest time ie: 45 DAT and 90 DAT for beans and Tomatoes respectively. The yield parameters recorded were number of pods, fresh weight of pods, dry weight of pods, harvest index for beans and number of fruits, average fruit weight, and average fruit weight for tomatoes.

Experimental Design Used: CRD

Treatment details:

T1 = Charcoal Production Soil

T2 = Adjacent Forest Soil

T3 = Jhumland Soil

No. of Replications: 07

The data collected were analyzed statistically using OPSTAT and MS Excel and the results were presented in tables and figures.

### 3.4.3 Impact of charcoal production and utilization on health aspects and resources availability

Charcoal production entails much strenuous work for the producer during felling, cross cutting, log haulage, kiln building and management. There are also risks associated with a carbonizing kiln particularly when repair work is being carried out. Another health risk to the producer as well as user is the exposure to gases and smoke and also heat from the kiln. Of all the gases emitted, Carbon Monoxide (CO) is the major health risk. In order to understand the impact of charcoal production and utilization on health aspects, questionnaire survey was conducted and the response of the respondents was recorded and analyzed.

The availability and status of raw materials of preferred woods and other resources for wood charcoal production were assessed through semi-structured questionnaire survey taking charcoal producers as the major respondents and the response were recorded and quantified. Accordingly, the data collected from different respondents were analyzed and presented with percentages and figures.

**Chapter 4**

# RESULTS

This chapter highlights the result of the investigation carried out through the field survey on various aspects of wood charcoal production and utilization in Mizoram and laboratory analyses of the charcoal and wood samples collected from the study site. The major findings on the environmental impact of charcoal production and utilization have also been presented along with supported tables and figures. However, environmental impact assessment was done evaluating some indirect effects such as implications of charcoal production on soil properties, yield and growth response of selected crops when grown in soil collected from charcoal production site, impact on health aspects of charcoal producers and consumers as well as effect on resource (wood biomass) availability. Despite long term trade on charcoal in Mizoram, no scholarly research has yet done to address social, environmental and institutional trends impacting rural areas with respect to charcoal production. Given the state's significant dependence on this fuel as well as the major economic impact on the charcoal industry itself, the following section identifies the livelihood challenges facing rural communities who participate in charcoal production for income generation, the quality attributes of the charcoal produced, and its environmental impact especially on soil health, health attributes of producers and consumers and on the resource availability for charcoal production.

### 4.1.1 Characteristics of charcoal trade

The study revealed that the charcoal trade chain in Mizoram starts from the producers, who are usually agricultural farmers from the villages. Producers are individuals that burn the firewood to produce charcoal. The charcoals are produced from jhumland in conjunction to agricultural farming so that it serves as the additional income earning opportunity. The produced charcoal are stacked on roadside of farmland which are then collected and retailed by either the middlemen who are from their respective villages or those operated from urban and sub-urban areas. The middlemen deliver the charcoal by vehicles to the stockists/retailers which sale to the end users in small and large quantities depending on the requirements (**Fig. 4.1**).

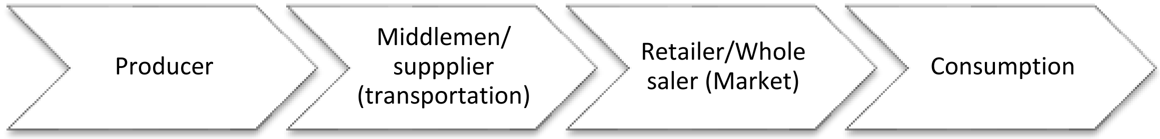



**Figure 4.1:** Characteristics of charcoal trade

### 4.1.2 Charcoal supply chain

Charcoal is a highly commercialized commodity which can be transported economically over long distances. Our study indicates that only a small proportion of households produce charcoal for own use, while the majority of products are mainly sold to towns and Aizawl city in the state for different heating energy purposes. The most common charcoal supply chain consists of three levels. First the transporters visit the production site or a designated collection point with a motorised or non-motorised means of transportation and buy the charcoal in bulk. They then transport the charcoal to vendors (wholesale or retail) mostly in urban areas. In the survey findings there are cases that the charcoals were also directly sold to the charcoal vendors via transporters as well as directly to households, food businesses and other customers including consumers by the producers who are residing in the Aizawl city and other towns (**Figure 4.2**).

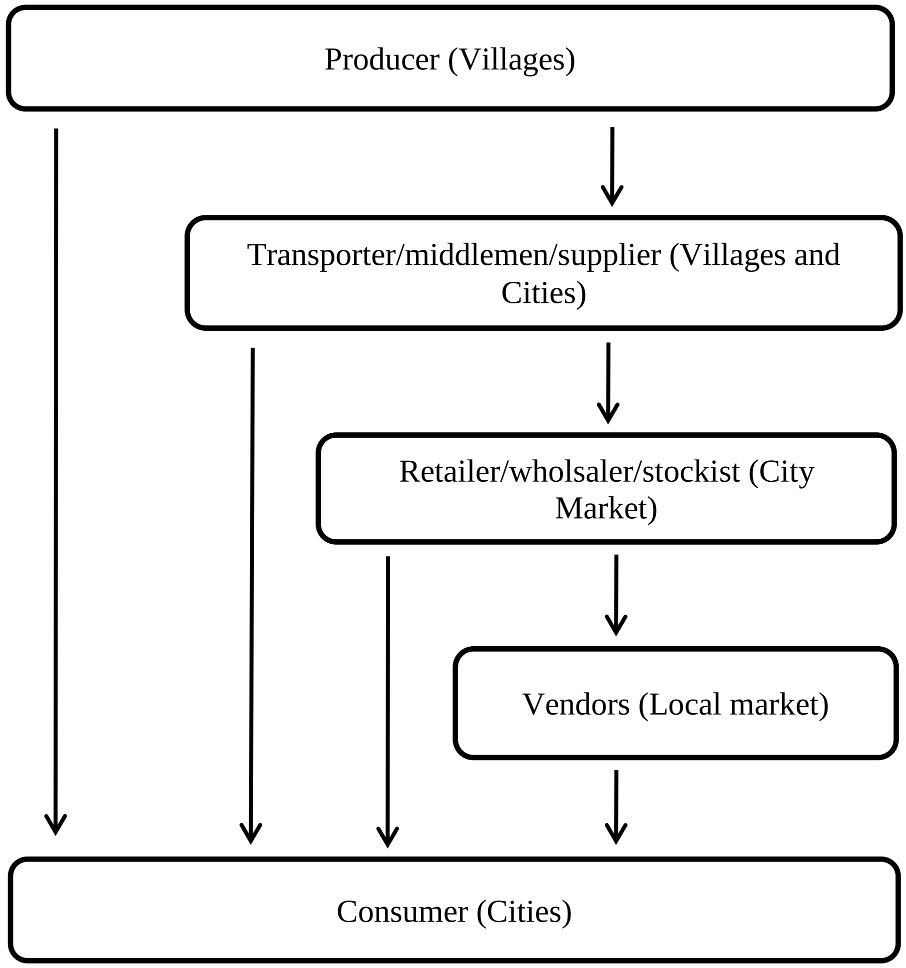



**Figure 4.2:** Charcoal supply chain

### 4.1.3 Charcoal production areas

According to the survey conducted during the study, It was found that majority of commercial charcoal production were normally located in rural villages, especially on the eastern side of Mizoram, i.e. Champhai district. This restriction is due to the fact that the copius availability of choice of tree species such as *Lithocarpus spp* and *Quercus spp* for making charcoal; hard and dense wood vegetations inhabited in these areas. It is also revealed that those villages which are producing large amount of charcoal were situated either within or nearby the forest protected areas. On the other hand, due to the scarcity of preferrable wood, several villages are also producing charcoal from less species which are readily availaible within their specified jhumlands.

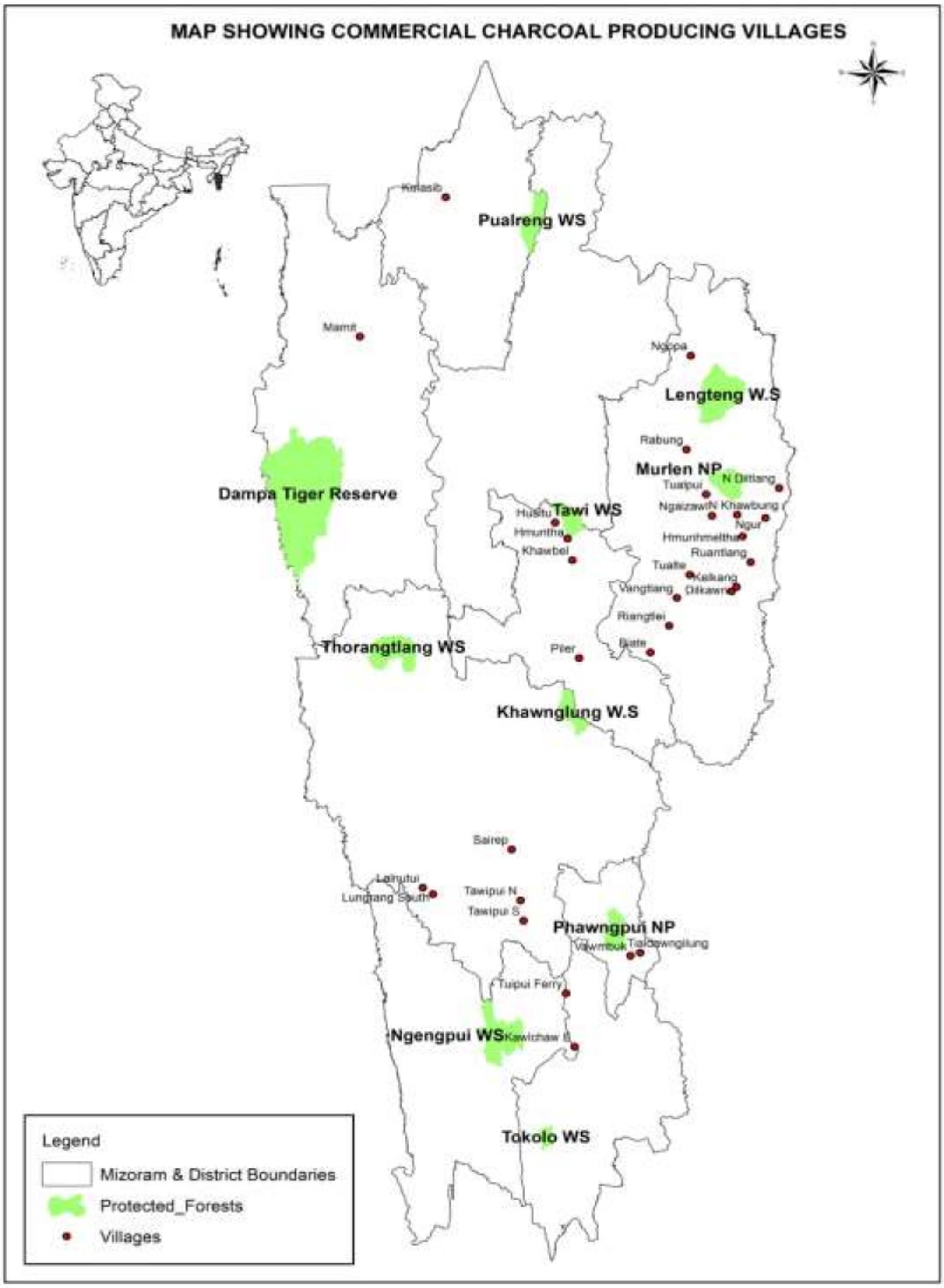



**Figure 4.3:** Geo-referenced map of identified commercial charcoal production villages in Mizoram (*Courtesy of MIRSAC, Mizoram*)

### 4.1.4 Households engaged in charcoal production

The producers from each districts were quantified in percentages; the survey data shows that each villages has some percentages of producers from the total households who are regularly engaged in the commercial charcoal production. Serchhip district shows highest number of producers (29.41% of total households) within the district in comparison to the size of households in percentage, although Champhai district is having the highest producer in numbers (24.38% of total households) but it comes second in household wise (**Figure 4.4**).

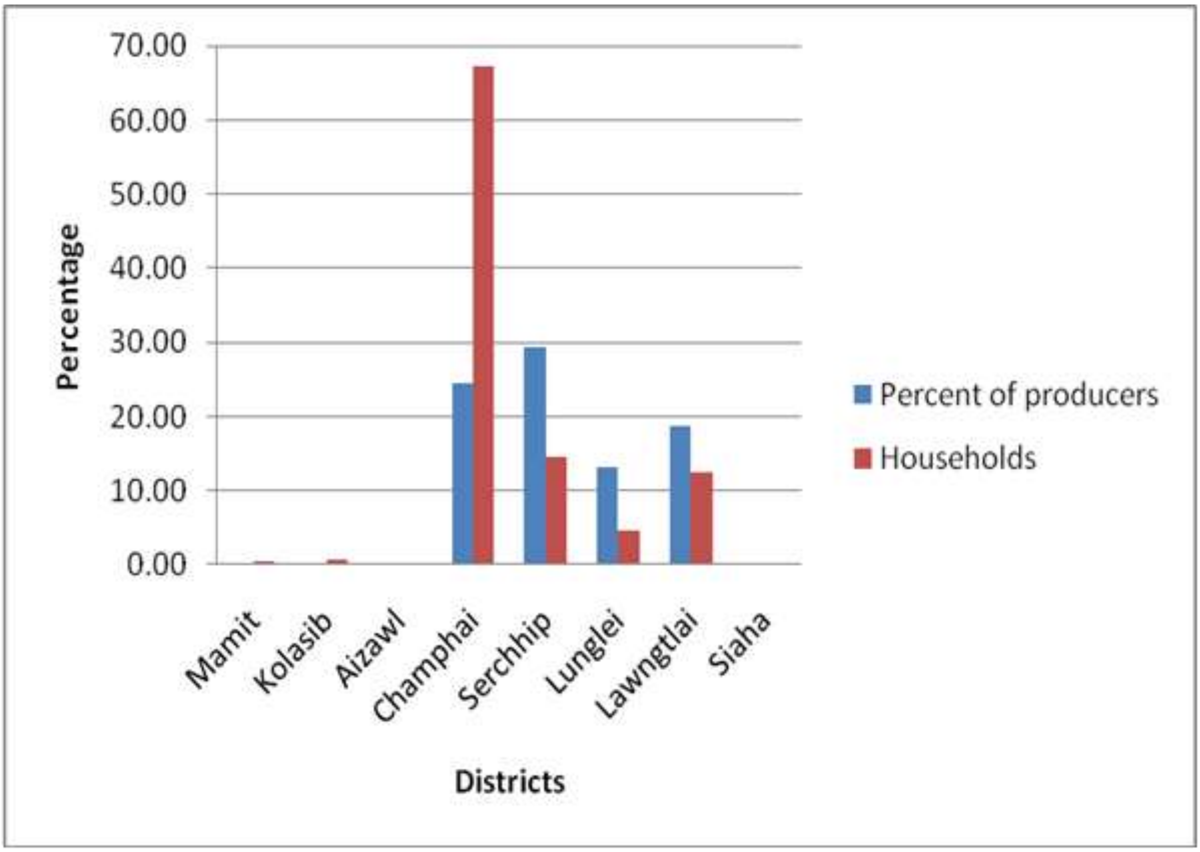



**Figure 4.4:** Households engaged in charcoal production (percentage of total households) 2015-16

### 4.1.5 Commencement of commercial charcoal production.

Through intensive data collected by questionnaire, it is found that the early commercial charcoal production was started from the villages of Kelkang and

Dilkawn in Champhai district. However, there were some records that productions were also taken place in some other villages like Tlangsam and some other villages of Champhai district but it was in small scale. Simultaneously, the commercial production was taken place in other villages where the peak production was observed to be started from the year between 2010 and 2015.

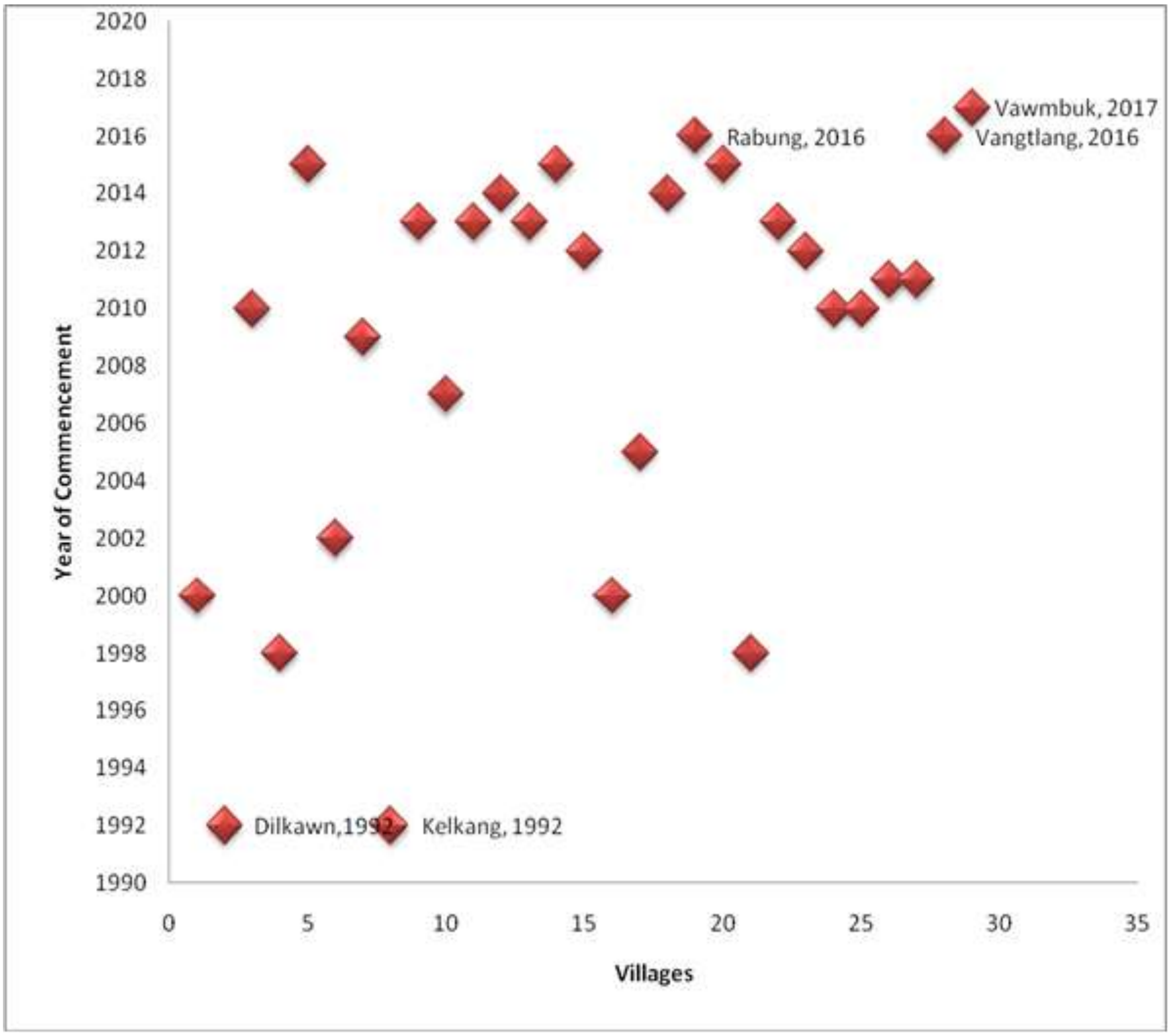



**Figure 4.5:** Year of commencement of commercial charcoal production in identified villages

### 4.1.6 Choice of tree species utilized for charcoal production

According to the frequency of species preference given by the respondents, the most preferred species for charcoal production was *L. dealbatus* followed by *L. polystachyus*. Most of the preferred species belongs to the family Fagaceae, but there are some other species utilized as additional raw materials currently being used for charcoal production namely: *Schima wallichii, Litsea monopetala, Albizia chinensis, Bauhinia variegata*, etc.

The major reasons for the use of such species are the quality of charcoal produced and the abundance of the species in the area. Other reasons, cited less frequently, were the clients' preference and the long lasting characteristics of the charcoal produced using the species. In most of the charcoal producers of Champhai district, the abundance of the species is the second major reason, while in other districts there are still more options. Therefore, producers can select the species that produce good quality charcoal (**Table 4.1**).

**Table 4.1:** Tree species utilized for charcoal production

| Sl No | Scientific Name | Family Name | Common /Vernacular Name | Local Name | Ranks as per respondents |
|---|---|---|---|---|---|
| 1 | *Castanopsis tribuloides* (Sm.) A.DC. | Fagaceae | Chinquapin | Thingsia | 5 |
| 2 | *Quercus helferiana* A.DC. | Fagaceae | Ring cupped oak | Hlai | 3 |
| 3 | *Lithocarpus pachyphyllus* (Kurz) Rehder | Fagaceae | Thick leaved oak | Thensen | 4 |
| 4 | *Lithocarpus polystachyus* (Wall. ex A.DC.) Rehder | Fagaceae | NA | Thil | 2 |
| 5 | *Lithocarpus dealbatus* (Hook.f. & Thomson ex Miq.) Rehder | Fagaceae | Oak | Fah | 1 |
| 6 | *Bauhinia variegata* L. | Leguminosae | Kachhnar | Vaube | 10 |

| | | | | | |
|---|---|---|---|---|---|
| 7 | *Wendlandia grandis* (Hook.f.) Cowan | Rubiaceae | Tilki | Batling | 7 |
| 8 | *Litsea monopetala* (Roxb.) Pers. | Lauraceae | Meda | Nauthak | 8 |
| 9 | *Emblica officinalis* Gaertn. | Phyllanthaceae | Aonla | Sunhlu | 9 |
| 10 | *Schima wallichii* Choisy | Theaceae | Schima | Khiang | 6 |
| 11 | *Anogeissus acuminata* (Roxb. ex DC.) Wall. ex Guillem. & Perr. | Combretaceae | Yon | Zairum | 6 |
| 12 | *Albizia procera* (Roxb.) Benth. | Leguminosae | White siris | Kangtek | 7 |
| 13 | *Derris robusta* (DC.) Benth. | Leguminosae | Korai | Thingkha | 7 |
| 14 | *Bursera serrata* Wall. ex Colebr. | Burseracea | Murtenga | Bil | 10 |
| 15 | *Messua ferrea* L. | Calophyllaceae | Ironwood tree | Herhse | 11 |
| 16 | *Euphoria longan* (Lour.) Steud. | Sapindaceae | Litchi | Theifeimung | 12 |
| 17 | *Heritiera papilio* Bedd. | Malvaceae | NA | Thingsaiphaw | 12 |
| 18 | *Betula alnoides* Buch.-Ham. ex D.Don | Betulaceae | Alder birch | Hriang | 11 |
| 19 | *Myrica esculenta* Buch.-Ham. ex D. Don | Myricaceae | Box myrtle | Keifang | 13 |
| 20 | *Albizia chinensis* (Osbeck) Merr. | Leguminosae | Siris | Vang | 12 |
| 21 | *Stereospermum colais* (Buch.-Ham. ex Dillwyn) Mabb. | Bignoniaceae | Padri | Zih nghal | 14 |
| 22 | *Vaccinium sprengelii* (G. Don) Sleumer | Ericaceae | NA | Sir-kam | 11 |
| 23 | *Ailanthus grandis* Prain | Simaroubaceae | Gokul | Thingarthau | 14 |
| 24 | *Homalium ceylanicum* (Gardner) Benth. | Salicaceae | NA | Thinglung | 12 |

### 4.1.7 District wise tree species utilized for charcoal production

Nonetheless, demand for charcoal is prevalent in most of the areas in Mizoram, hence, charcoal are procured either from other districts which produced preferred quality of charcoal or produced within their respective localities with the available raw materials notwithstanding the preferable species. Therefore, the species utilized are more or less same in every district; however, each district has its own respective species utilized for charcoal making due to the variation in species composition of vegetation in several districts. For instance, due to lack of those preferred trees, districts of Kolasib, Mamit and Lunglei are utilizing more or less dense wood such as *S. wallichii, D. robusta, A. acuminata, C. arborea* etc. for production, which in turn is considered to produce low quality of charcoal.

**Table 4.2:** District wise list of tree species for charcoal production

| **District** | **Major wood species** |
|---|---|
| Mamit | *Castanopsis tribuloides, Schima wallichii, Anogeissus acuminata, Messua ferrea, Euphoria longan, Heritiera papilio.* |
| Kolasib | *Derris robusta, Anogeissus acuminata, Albizia procera.* |
| Aizawl | *No production* |
| Champhai | *Castanopsis tribuloides, Lithocarpus dealbatus, Quercus helferiana, Lithocarpus pachyphyllus, Lithocarpus polystachyus, Wendlandia grandis, Schima wallichii, Derris robusta, Quercus dilatata, Litsea monopetala, Betula alnoides, Myrica esculenta, Albizia chinensis, Bauhinia variegata, Stereospermum colais, Vaccinium sprengelii, Ailanthus grandis* |
| Serchhip | *Castanopsis tribuloides, Lithocarpus dealbatus, Quercus helferiana, Lithocarpus pachyphyllus, Lithocarpus polystachyus, Wendlandia grandis, Schima wallichii, Derris robusta, Albizia procera* |
| Lunglei | *Anogeissus acuminata, Schima wallichii, Derris robusta, Callicarpa arborea* |
| Lawngtlai | *Lithocarpus dealbatus, Lithocarpus polystachyus, Castanopsis tribuloides, Lithocarpus pachyphyllus, Quercus helferiana, Schima wallichii, Stereospermum colais, Homalium ceylanicum* |
| Siaha | *No production* |

### 4.1.8 Preferred choice of tree species used for charcoal production

Producers normally use the whole tree, cut into certain length and the species used are dependent on the availability in the area, mainly from jhum land. **Table 4.3** shows the frequency of use of different species for charcoal production based on the response of the interviewees. The highly preferred tree species based on use frequency and respondents ranking were found to be *L. dealbatus, L. polystachyus, Q. helferiana, L. pachyphyllus* and *C. tribuloides,* because of their high density and availability. On the other hand, other species were also found to be utilized as additional in several production areas due to shortage and absence of the preferred species.

**Table 4.3:** Respondents choice of species

| Scientific Name | Frequency | Rank |
|---|---|---|
| *Lithocarpus dealbatus* | 34 | 1 |
| *Lithocarpus polystachyus* | 30 | 2 |
| *Quercus helferiana* | 28 | 3 |
| *Lithocarpus pachyphyllus* | 26 | 4 |
| *Castanopsis tribuloides* | 23 | 5 |
| *Schima wallichii* | 17 | 6 |
| *Wendlandia grandis* | 12 | 7 |
| *Litsea monopetala* | 9 | 8 |
| *Emblica officinalis* | 8 | 9 |
| *Bauhinia variegata* | 7 | 10 |

### 4.1.9 District wise charcoal production site and method used

Although there is charcoal production from 6 districts (Mamit, Kolasib, Champhai, Serchhip, Lunglei and Lawngtlai), the majority of charcoal that feed Aizawl urban markets is currently coming from Champhai and Serchhip districts. There is no commercial producer identified in Aizawl district (**Table 4.4**). It is remarkable that since the Council prohibited producing charcoal within their district, Siaha charcoal demand is supplied by the producers from outside their district located in Lawngtlai district. Small amount of production is identified in Kolasib district to meet the domestic requirement, it is however, learnt from the respondents that the majority of charcoal supply comes from Champhai district and few amount of low quality charcoal were procured from Assam *via* Vairengte. The source of material and place of production also varied with districts, while in most of the districts charcoal is produced mainly by individual from their respective jhumlands whereas production was observed from private land in Mamit. As in the case of Mamit district, there was a single person who owned a vast area of land, producing charcoal from his land as and when required.

**Table 4.4:** District wise charcoal production site and method used

| **District** | **Production site** | **Method** |
|---|---|---|
| Mamit | Own Land | Pit method |
| Kolasib | Own land and from Assam via Vairengte | Pit method |
| Aizawl | NA | NA |
| Champhai | Jhum Land | Pit and kiln methods |
| Serchhip | Jhum Land | Kiln method |
| Lunglei | Jhum Land | Pit method |
| Lawngtlai | Jhum Land | Pit method |
| Siaha | NA | NA |

### 4.1.10 Average quantity of charcoal produced

The average quantity of charcoal produced varied district wise wherein the highest production was recorded in Champhai district (247950 bags/month). The lowest production was found Kolasib district (45 bags/month) (**Table 4.5**). The quantity of charcoal per bag also found to vary and ranged from 18 – 25 kg. Similarly district wise variation in the selling price of charcoal at the production source was also observed which ranged from Rs.245 – Rs. 500/bag.

**Table 4.5:** Average quantity of charcoal produced during 2015-16

| District | Average quantity produced (bags/month) | Average Selling Price (Rs.) | Selling Point/ Area |
|---|---|---|---|
| Mamit | 300 | 500 | Mamit (Local) |
| Kolasib | 45 | 290 | Kolasib (Local) |
| Aizawl | NA | NA | NA |
| Champhai | 247950 | 310 | Aizawl, Champhai, Lunglei, Serchhip, Kolasib |
| Serchhip | 51000 | 275 | Aizawl, Serchhip |
| Lunglei | 9075 | 250 | Lunglei (Local) |
| Lawngtlai | 46800 | 245 | Siaha, Lawngtlai |
| Siaha | NA | NA | NA |

### 4.1.11 District wise charcoal producing villages

The survey collected information from the different district villages and headquarters of Mizoram shows significant variations in amount of charcoal production and the distribution is shown in **Figure 4.6**. The data shows that majority of charcoal production villages (52%) were in Champhai district represented by 13 villages, followed by Serchhip and Lunglei districts with 16% each and Lawngtlai district in the southern region (2%).

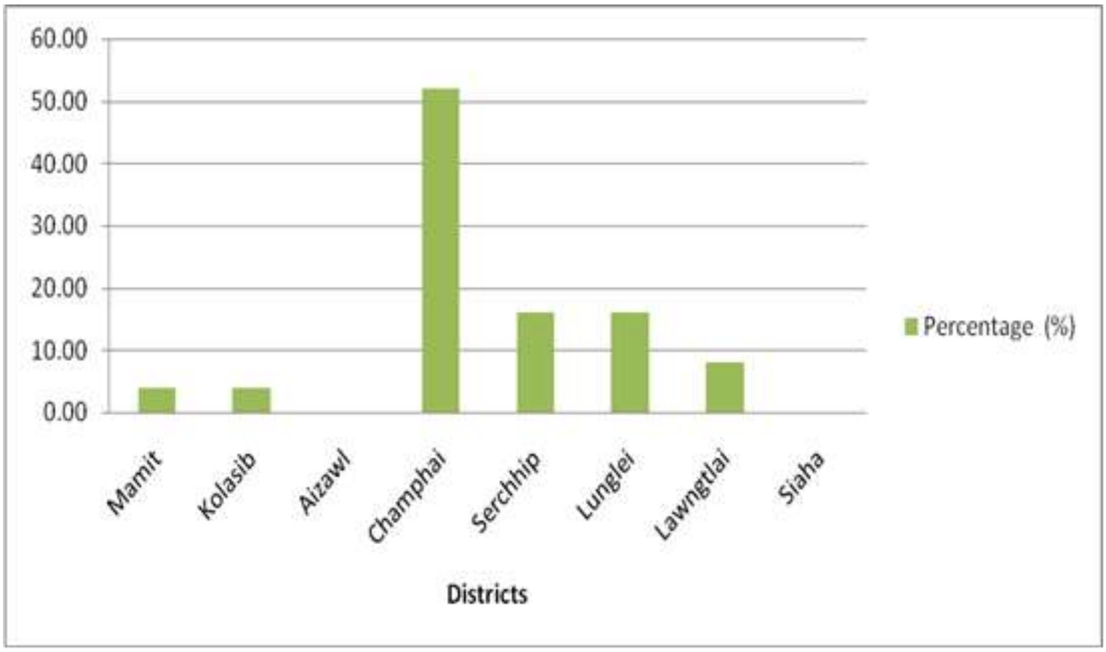



**Figure 4.6:** District wise charcoal producing villages (percentage of total no. of villages producing wood charcoal)

### 4.1.12 Mode of Charcoal Transportation

Charcoal is being transported all over the year but the warm season (late March – late September) of the state is the period with less quantities being transported due to the less demand of charcoal during this time and difficulty to access the production areas due to monsoon rains which also cause decrease in prices of charcoal in the markets. Hence, within the study sites, the most common forms of transport observed were pickup (28.4%).

As a result of the distance to the markets, charcoal transportation costs are increasingly becoming higher and may at a certain point in time become transporters normally function as middlemen and retailers. This category includes individuals that carry the charcoal from the production areas to the district headquarters using pick up (1500kg payload), 407 (2915kg payload), 207 (1040kg payload), LPK (2590kg payload), trucks and even maxi cab transport charcoal from the district headquarters to the main markets in city. From the observation Mahindra Pick up was found to be the major mode of transporting charcoal from production source to different areas of the state (**Figure 4.7**). According to research observation, transporters can be divided into different groups:

- People from production villages that own one or more vehicles and transport their own products - normally buying from producers to resell in city and towns.
- People who dedicate themselves to buying the charcoal in the rural areas and reselling it in the city. They don't have their own transport and can use either rented carriages for the charcoal transportation. They are usually women and operated from towns or city.
- People who transport the charcoal from the producer to retailers or end user by means of maxi cab in less quantities (6-10 bags). They are the maxi cab driver servicing to and fro from city/town to production village.

Majority of transporters are "outsiders" from the production areas being most of them living in urban and sub-urbans. Few are operating from their own respective villages, especially those who own vehicle and transport the products within an interval period of time.

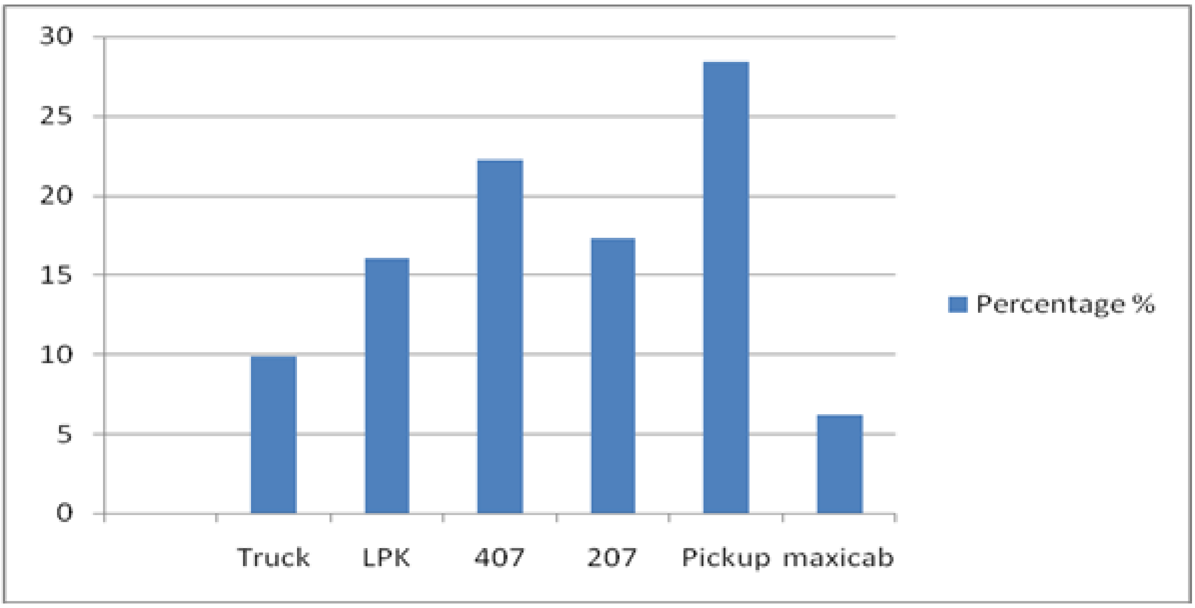



**Figure 4.7:** Mode of Transportation from production site to marketing points

### 4.1.13 Commercial charcoal retailers

Retailers buy the charcoal in bags from the transporters or middlemen and resell it in bags or small poly bags. They can be found in specific location in the city and towns. Although there is uniformity in the prices of charcoal within the same area, there is still lack of uniformity on the sizes used for the charcoal packaging which are decided by the transporters who decide on the quantities that are fed into the bags. The data in **Figure 4.8** shows that majority of charcoal selling store (48%) are in Aizawl, followed by Champhai with 24% and Siaha 8%. This shows that Aizawl, the capital city has the largest market for charcoal since it is the largest single urban settlement in the country. Some of the wholesaling places belong to the transporters or the producers that are involved in the whole supply chain.

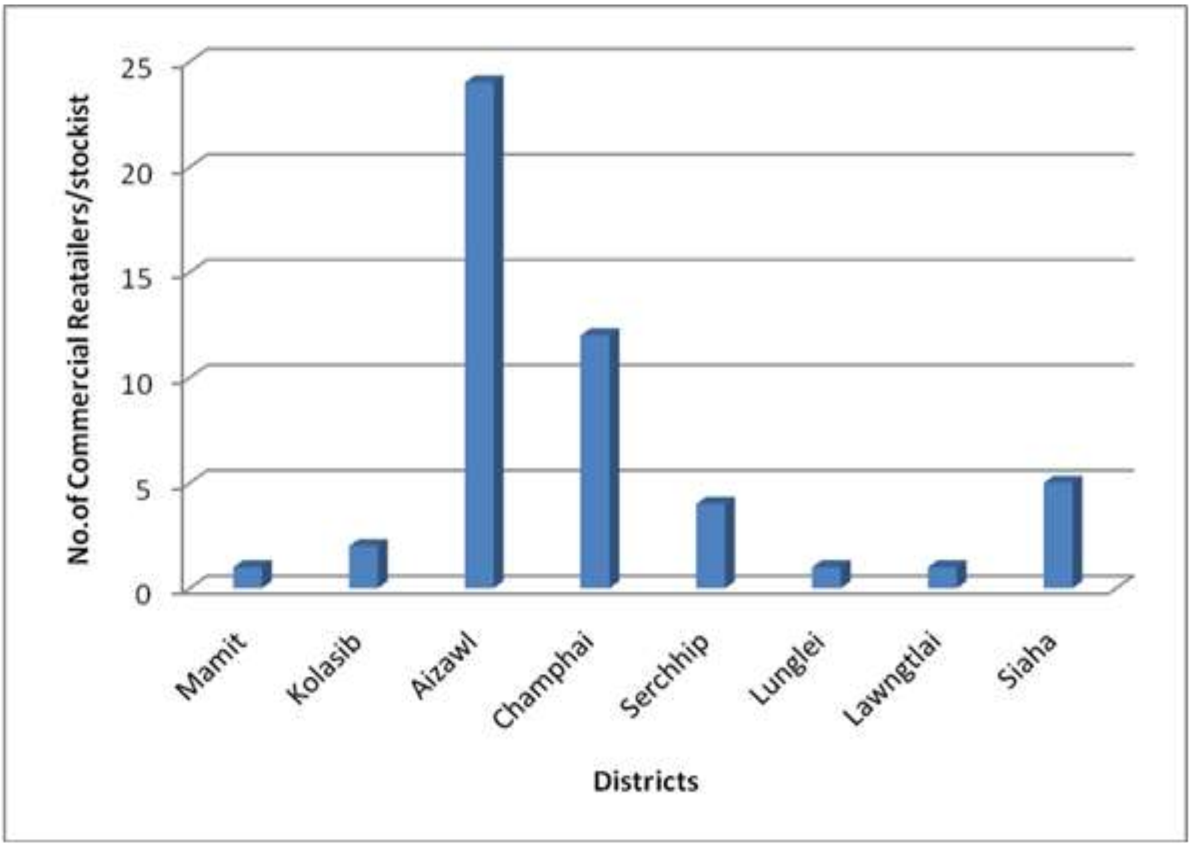



**Figure 4.8:** No. of commercial charcoal retailers identified during 2015-16

#### 4.1.14 Charcoal market demand

Market trends normally follow the demand trends; during the winter season, charcoal demand becomes more, thus the charcoal prices also tend to rise. In addition charcoal prices vary, among others, depending on the area where the charcoal is being sold, and the origin of the charcoal as well as the species used. Aizawl has the largest market for charcoal (48%) (**Figure 4.9**) as it is the city and has diverse applications. However, the demand in most of the district is directly related with the cold season as many households are still using charcoal for space warming.

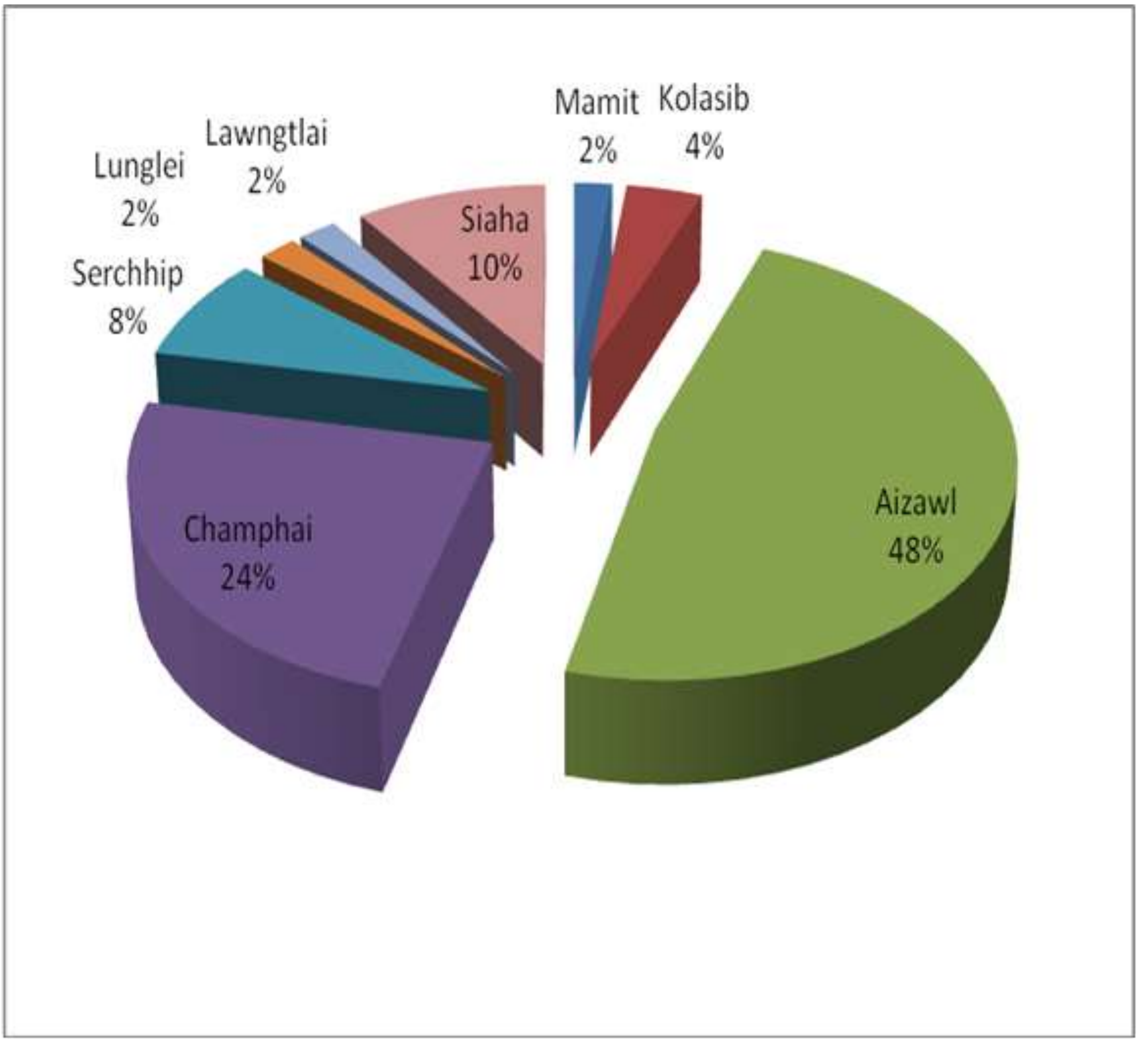



**Figure 4.9:** District wise charcoal demand (%)

### 4.1.15 Charcoal consumption pattern

Charcoal consumers are normally located in the urban and peri-urban areas and may be divided into two different groups i) Domestic - those who use it for cooking and heating the houses and ii) large/industrial consumers - those who use charcoal to cook or generate heat for industrial processes such as local distilleries, restaurants, hotels, hostels, fast food outlets, etc.

The study revealed that the major users of charcoal in the entire urban area of the study site were still dependent on biomass energy despite there was sufficient supply of such energy supplements such as electricity and LPG. From the questionnaire survey the supply of charcoal and retailers' main markets were found to be tea stall/canteen (39.53%) (from the total respondents; n=339), households (space warming) contributed to 27.43%, local distilleries and blacksmiths at several places of the survey area put into 8.55% and 7.67% respectively, hostels also contributed 5.31% and 2.06% by other commercial usages (**Figure 4.10**).

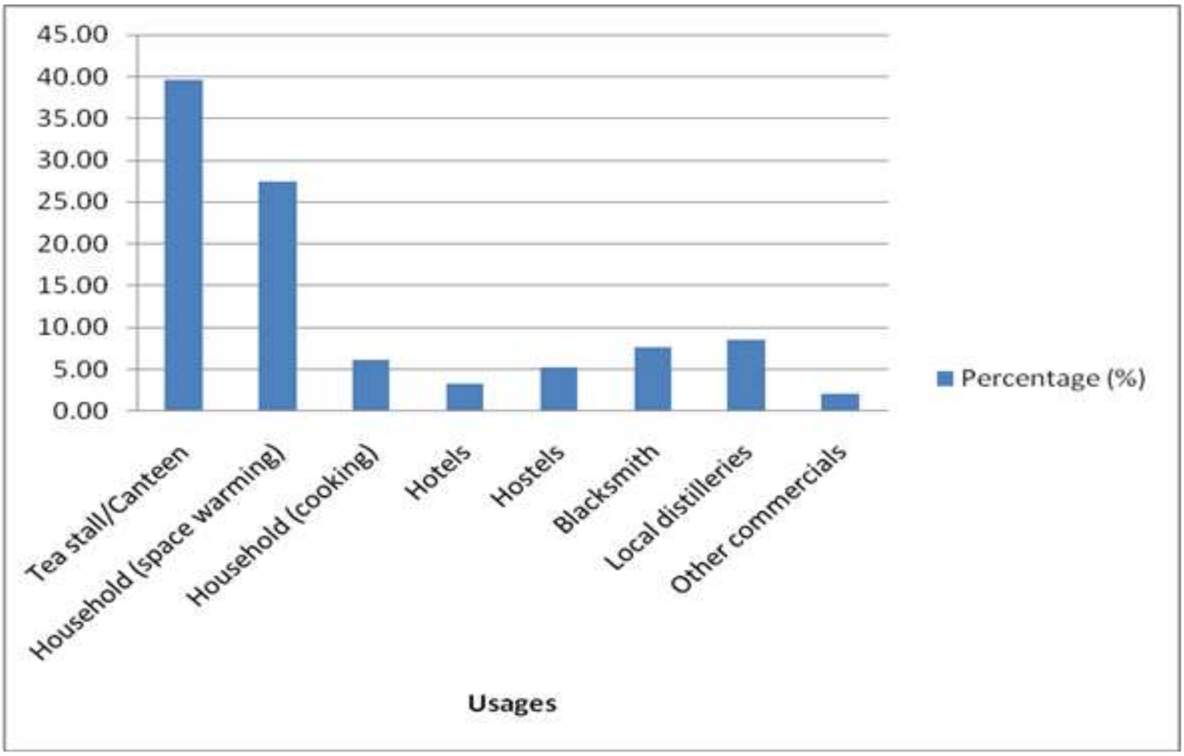



**Figure 4.10:** Wood charcoal consumption pattern (major usage in percent of the total respondents)

### 4.1.16 Gender role in charcoal trade

Most of the producers live in remote areas, close to the resources. Only a few women are involved in the production process because the activity is considered labor-intensive. Women are involved mainly to help their husbands/male counterparts in the family while cross cutting the logs and tending the kilns/pits. However, survey revealed that from the respondents (n=80) the more percentage of female (67.5%) involved in charcoal business as middlemen, stockists or retailers and only 32.5% were male. It was also observed that majority were operating from the capital, i.e. Aizawl. Mainly women in the age group of 30-50 years were engaged in retail business. However, about 23% from the total surveyed respondents of Lawngtlai district was male (**Table 4.6**). In general, more women were involved in charcoal trading than men in most of the areas.

**Table 4.6:** Persons involved in charcoal business (middlemen & stockists) during 2015-16

| District | Male % | Female % | Female percentage to the total |
|---|---|---|---|
| Mamit | 3.85 | 0.0 | 0.0 |
| Kolasib | 3.85 | 5.56 | 75.0 |
| Aizawl | 19.23 | 40.74 | 81.5 |
| Champhai | 15.38 | 24.07 | 76.5 |
| Serchhip | 19.23 | 5.56 | 37.5 |
| Lunglei | 7.69 | 9.26 | 71.4 |
| Lawngtlai | 23.08 | 9.26 | 45.5 |
| Siaha | 7.69 | 5.56 | 60.0 |
| **Total** | **100.00** | **100** | **67.5** |

### 4.1.17 District wise percentage of people's involvement in charcoal trade

Due to the unorganized nature of the activity, it is difficult to estimate the numbers of people involved in this trade. According to the survey result, maximum number of people engaged in charcoal trade was identified in Aizawl city (33.75%), and followed by Champhai (21.25%) and Lawngtlai (13.75%) (**Figure 4.11**).

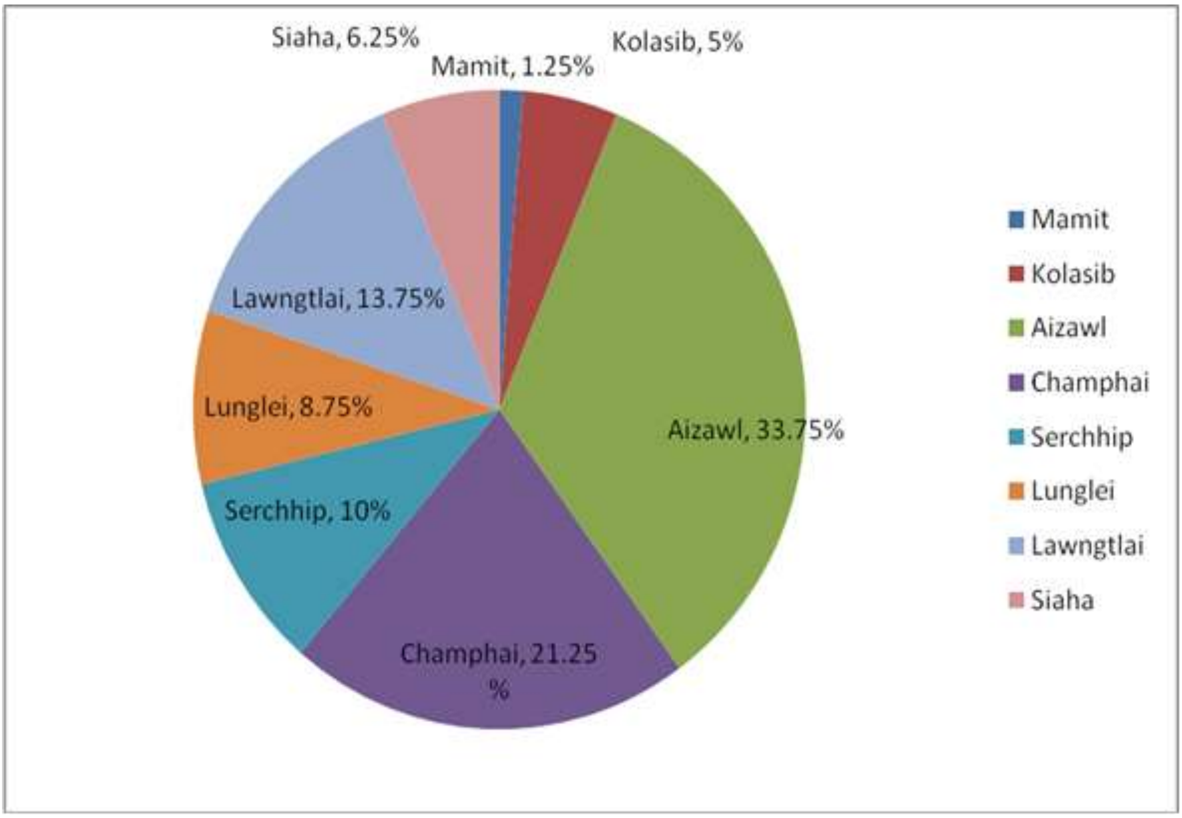



**Figure 4.11:** Persons involved in charcoal business (district wise percentage) during 2015-16.

### 4.1.18 Charcoal production system

Though charcoal production is prevalent in most of the identified production area in Mizoram, yet it is observed that the peak production is rather seasonal since the demand is usually increases during rainy season and winter; as such charcoal production rate is at climax during this time of year. The rests are off-season months for agriculture and cover the period of June through October. Charcoal production is usually done to supplement farm income which is the major economic activity. On the average, each household produces about 120 bags a month, mostly for sale. No charcoal is produced intentionally for home use except that which is left after sale and usually it is very minimal. The charcoal making process is usually done in jhum lands which involves wood cutting during land preparation for farming, kiln preparation, carbonisation and finally unloading charcoal from the kiln. Source of labour for charcoal making activities is mainly household labour, where the males are usually the main worker and occasionally accompanied by wife and children. However, there were some observations where the charcoals are produced within private land by the owner from their own resources depends on the demand of the area. The study revealed that in Mizoram, charcoal is usually produced by two methods *viz.* pit and earth kiln.

**A. Charcoal Production by Pit Method**

The *pit* method is the old and traditional method of producing charcoal since longtime back. It was the most common method and utilized till now in different areas. It is made by digging a pit or excavated land (sometimes small gullies/drainage are also employed) where a pile of logs are stacked, providing chimneys for smoke outlet at the edges, igniting the wood and covered with earth and litters, then allowing carbonization under limited air supply for a period of time. The time required for preparation of this method is usually a day; it is a fast and easy method but less efficient production. The following stages were involved in the production of charcoal in most communities in Mizoram.

a) Site preparation
b) Wood preparation
c) Wood stacking and covering
d) Wood carbonization
e) Charcoal harvesting and bagging.

**i) Site preparation**

The site is usually prepared within the jhum land or own land where the woods are close by. In case of leveled land a pit of irregular convex pentagon shape is usually dug with 3ft deep by using spade and digging hoe. Both the opposite sides are prepared in such a way that they are sloping down inwards intersecting at the middle where the air passing line/conduit is created at the middle from the bottom to the pointed edge upwards. Slight sloping from top edge to the bottom is also maintained so as the wood will get burnt from bottom to top when lighted. Size of the pit varies with as per desired.

**ii) Wood preparation**

Wood used for charcoal production is generally obtained by felling trees on farmlands. With respect to tree felling, trees are often crosscut into billets of 1.0-1.5 m lengths. Wet wood often produces greater yield charcoal than dry wood but time for carbonization is longer.

**iii) Wood stacking and covering**

Pieces of dry wood are often laid on the ground first for easy ignition of the mound and the large pieces are then stacked on these pieces. Dry twigs are burnt in this hole to initiate carbonization. The covering of the wood stack with litters is for the clogging of spaces in the wood stack in order to allow free air draught in the mound especially during the carbonization stage. The stack is completely covered with loose earth except 3-4 air outlets at the edges. During the stacking and covering of the wood, hole and air inlets are created where fire is inserted.

**iv) Wood carbonization**

The wood stack is lit at the bottom so as to facilitate the wood to burn upwards. The intensity of smoke from the holes are observed cautiously and when the smoke become more or less transparent, the holes are closed with the loose soil leaving only one hole open. Carbonization is the process of combusting part of wood until it is hot enough to be able to react exothermically in a limited air supply. The method of carbonization is to upgrade the value of wood as fuel energy. Charcoal is produced as a result of the chemical reduction of organic material under controlled condition. Complete carbonization takes about 5-7 days depending on the size of mound and the moisture content of wood.

**v) Charcoal harvesting**

At the end of carbonization, the producer harvests the charcoal by first removing the loose earth and the grass. The charcoal was covered by soil immediately upon removal from the kiln to prevent spontaneous ignition and burning the charcoal to ashes. Often water is used to put off/cool down the hot and sometimes still burning charcoal. When the fire in the charcoal is put off, it is allowed to cool down; it is then filled into a jute sacks and ready for conveyance.

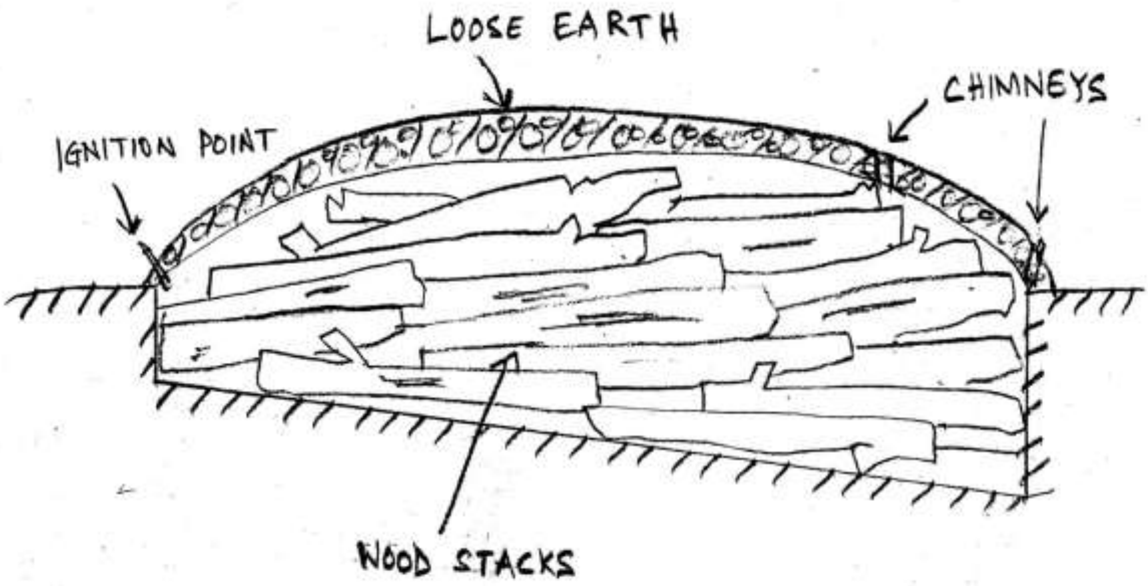



**Figure 4.12:** Side view of Traditional Pit method

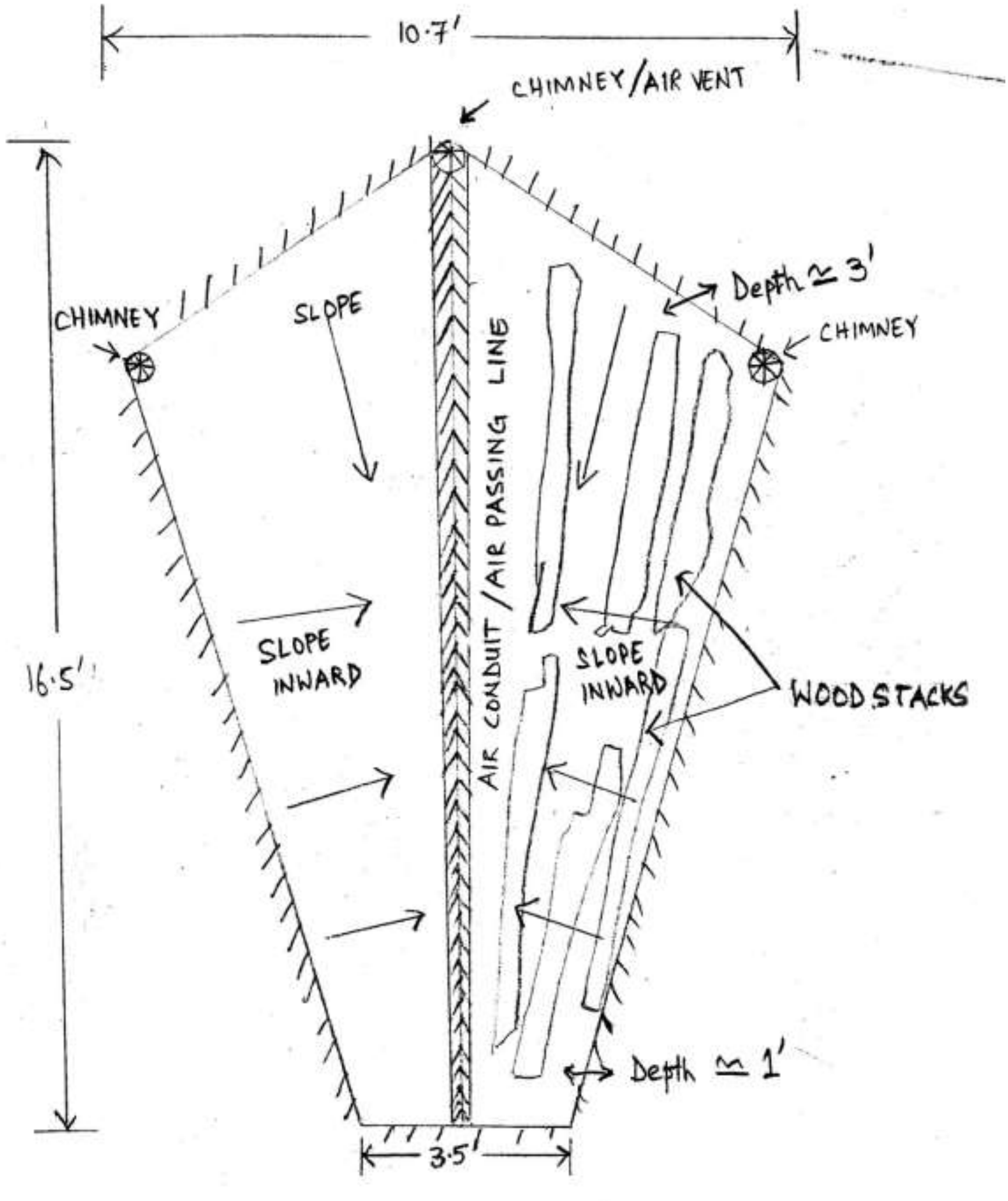



**Figure 4.13:** Top view of Traditional Pit method

### B. Charcoal Production by Earth Kiln

The traditional earth kiln is the most conventional method in those areas which produce charcoal in large scale. According to respondents, the technique is a modified method from the technology introduced by the Japanese which was actually meant for producing wood vinegar. However, the technology was later customized and employed for producing charcoal in commercial scale. The method was gradually conveyed to one village to another thereby the old method i.e. pit method, was slowly less employed except in limited areas. In this method hole is dug on the slope with digging tools thus literally creating a kiln inside the earth. Two air outlets of main and additional chimneys are created at the top of the kiln where the later is closed with earth-turf after 2-3 hrs when burning continues. The entrance is also made to facilitate entering and hauling in and out the material. This entrance is also closed simultaneously closing with the smaller chimney leaving a small opening with earth turf. The smoke on the main chimney is observed for 2-3 days and when it become less thick, the main chimney is also closed. Finally, the only hole left opening is the small hole at the entrance wall. The carbonization process takes about 1 week, after that the charcoal is also ready for harvest.

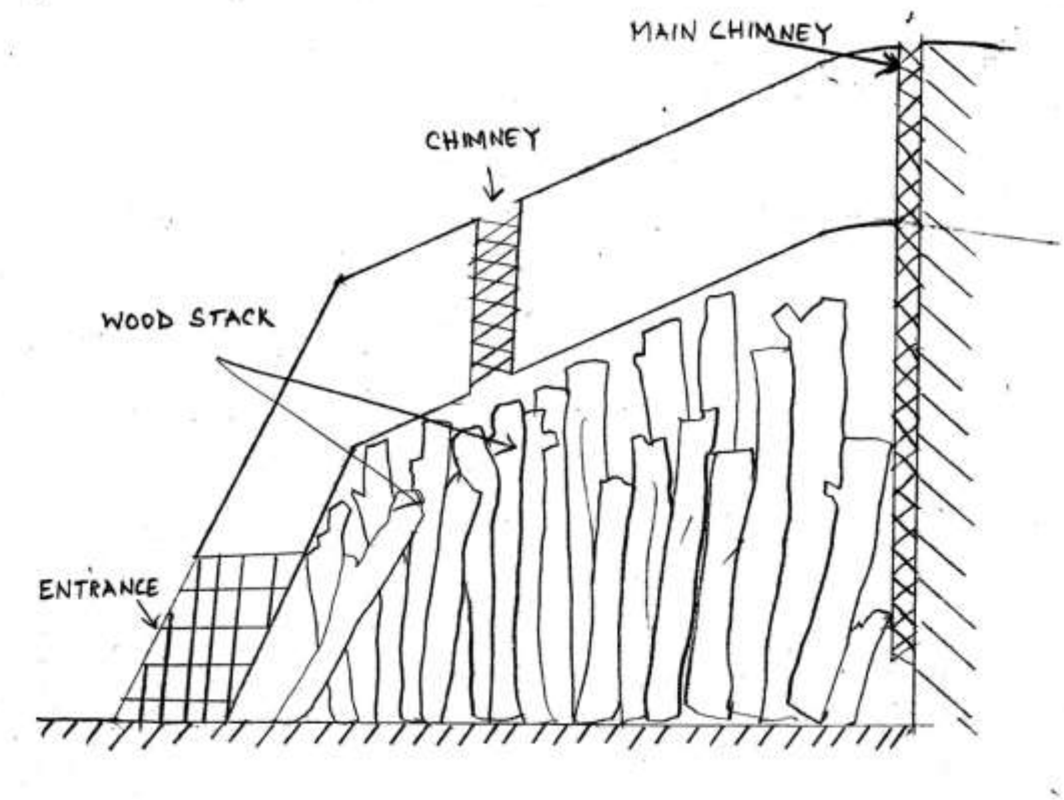



**Figure 4.14:** Side view of traditional earth kiln method

**Characteristics of Good Charcoal**

The physical and chemical properties of charcoal depend partly on the original materials from which it is made (species wise) and partly on the condition of the carbonization process. Most charcoal users prefer the hard, somewhat heavy in weight and uneasily breakable ones, which can be ignited readily and will continue to emit heat for a long time. The gross features also shows a shiny and glistening appearance, should give clear metallic note, do not blackened hands when contact. Producers who mix different charcoal (hard & soft) together obtain charcoal of acceptable quality. This gives them the 'proprietary blend'.

## 4.2 Assessment of charcoal quality

The air dried samples of ten major tree species preference wise were collected and cross-cut into logs of 1- 1.5m long and carbonized in traditional kiln method. The charcoal produced after carbonizations were collected species wise and further subjected to analysis for their physico-chemical properties.

### 4.2.1 Physico-chemical properties of charcoal

### 4.2.2 Bulk Density ($g/cm^3$)

Significant variation (P<0.05) was observed among the density of charcoal originated from studied species of Mizoram. Maximum density of charcoal was observed in *L. dealbatus* (0.363 $g/cm^3$) and minimum in *L. monopetala* (0.206 $g/cm^3$) (**Table 4.7**). The non significant groups with respect to the density of charcoal species studied were: among *L. pachyphyllus, B. variegata* and *L. monopetala*, among *S. wallichii*, *L. pachyphyllus* and *B. variegata*, between *S. wallichii* and *L. pachyphyllus*, among *Q. helferiana*, *L. polystachyus* and *W. grandis* and among *Q. helferiana*, *L. polystachyus*, *L. dealbatus* and *W. grandis*.

### 4.2.3 Moisture content (%)

The moisture content of all charcoal almost reduced to about 10% of moisture content of its respective wood sample (**Table 4.7)**. Further, there was highly significant variation (P<0.05) among the tree species with respect to the moisture content of their respective charcoals. The non significant groups as studied from statistical analysis were: among *C. tribuloides*, *S. wallichii* and *L. dealbatus*, between *W. grandis* and *E. officinalis*, among *Q. helferiana*, *L. pachyphyllus* and *W. grandis* and among *Q. helferiana*, *L. pachyphyllus*, *B. variegata* and *L. monopetala*.

### 4.2.4 Friability (%)

Friability is considered to be a qualitative parameter for charcoal marketability as learnt from the respondents. Further, laboratory analysis marked highly significant variations among the species with respect to their friability of charcoal. Highest friability (15.305%) was observed with *B. variegata* and the lowest friability (2.985%) was found with *L. dealbatus* (**Table 4.7)**. The non significant groups with respect to friability of charcoal were observed to be between *L. polystachyus* and *B. variegata*, among *C. tribuloides*, *Q. helferiana*, *S. wallichii*, *L. pachyphyllus* and *W. grandis*, between *C. tribuloides* and *L. monopetala* and between *L. monopetala* and *E. officinalis*.

#### 4.2.5 Carbon content (%)

The carbon content of charcoal exhibited a remarkable variation among the tree species studied with the highest value (85.306%) recorded in *L. monopetala* and the lowest (55.859%) was estimated in *S. wallichii* (**Table 4.7)**. The individual species showed significant variation ($P<0.05$) in carbon content of charcoal among each other. The order of carbon content of charcoal was observed to be *L. monopetala* (85.306%) > *C. tribuloides* (82.413%) > *E. officinalis* (80.887%) > *L. pachyphyllus* (80.293%) > *B. variegata* (78.228%) > *Q. helferiana* (77.077%) > *L. dealbatus* (72.78%) > *W. grandis* (67.51%) > *L. polystachyus* (65.359%) > *S. wallichii* (55.859%).

#### 4.2.6 Ash content (%)

Ash content of charcoal is considered as undesirable indicator for marketability. The highest ash content was recorded in *Q. helferiana* (6.077%) and the least was found in *S. wallichii* (0.728%) (**Table 4.7)**. The highly significant variation was observed among the species with respect to ash contents of their respective charcoals. However there was no remarkable variation in ash content of charcoal of tree species studied between *L. pachyphyllus* and *W. grandis*, between *L. monopetala* and *E. officinalis*, between *L. monopetala* and *E. officinalis*.

#### 4.2.7 Calorific Value (MJ/Kg)

Calorific value of charcoal was varying between 27.53 MJ/Kg in *S. wallichii* upto 29.943 MJ/Kg in *L. polystachyus* (**Table 4.7)**. Among the species, highly significant variation ($P<0.05$) among the species with respect to calorific value of charcoal was observed, some of the species recorded marginal difference with each other. The at per groups were: among *Q. helferiana*, *S. wallichii*, *L. dealbatus* and *B. variegata*, among *Q. helferiana*, *L. dealbatus*, *B. variegata* and *W. grandis*, among *B. variegata*, *W. grandis* and *L. monopetala* and between *C. tribuloides* and *E. officinalis*.

### 4.2.8 Volatile matters (%)

Among the species very high variation was observed with respect to the volatile matters in charcoal influencing their charcoal qualities. Highly significant difference ($P<0.05$) among the species was found with respect to their volatile matter content. The maximum volatile matter was recorded in *S. wallichii* (43.413%) and the minimum was estimated in *L. monopetala* (12.557%) (**Table 4.7)**. Volatile matter content in each species was significantly different from the other species.

**Table 4.7:** Variation of charcoal physico-chemical properties based on tree species in Mizoram

| Species | Density ($g/cm^3$) | Moisture Content (%) | Friability (%) | Carbon Content (%) | Ash Content (%) | Cal. Value (MJ/Kg) | Volatile matters (%) |
|---|---|---|---|---|---|---|---|
| *C. tribuloides* | 0.341[de] | 4.37[a] | 8.051[bc] | 82.413[h] | 2.467[f] | 28.87[d] | 15.12[b] |
| *Q. helferiana* | 0.346[de] | 5.76[cd] | 7.321[b] | 77.077[d] | 6.077[j] | 27.65[ab] | 16.847[c] |
| *S. wallichii* | 0.27[bc] | 3.9[a] | 7.716[b] | 55.859 | 0.728[a] | 27.537[a] | 43.413[j] |
| *L. pachyphyllus* | 0.257[abc] | 5.69[cd] | 7.696[b] | 80.293[f] | 1.537[b] | 29.513[e] | 18.17[e] |
| *L. polystachyus* | 0.331[de] | 6.72 | 4.754[a] | 65.359[a] | 4.635[i] | 29.943[f] | 30.007[h] |
| *L. dealbatus* | 0.363[e] | 4.42[a] | 2.985 | 72.78[c] | 3.013[gh] | 27.627[ab] | 24.207[g] |
| *B. variegata* | 0.236[ab] | 6.06[d] | 15.305[e] | 78.228[e] | 2.956[g] | 27.927[abc] | 18.817[f] |
| *W. grandis* | 0.337[de] | 5.44b[c] | 6.503[b] | 67.51[b] | 1.557[bc] | 27.987[bc] | 30.933[i] |
| *L. monopetala* | 0.206[a] | 6.18[d] | 9.396[cd] | 85.306[i] | 2.137[de] | 28.267[c] | 12.557[a] |
| *E. officinalis* | 0.307[cd] | 5.16[b] | 10.104[d] | 80.887[g] | 2.103[d] | 28.977[d] | 17.01[d] |
| **$SE_m$** | 0.025 | 0.255 | 1.656 | 0.125 | 0.118 | 0.190 | 0.056 |
| **$CD_{0.05}$** | 0.052** | 0.532** | 3.455** | 0.260** | 0.247** | 0.395** | 0.117** |
| **$CD_{0.01}$** | 0.0706 | 0.726 | 4.71 | 0.355 | 0.337 | 0.539 | 0.159 |

**Table 4.8:** Pearson's correlation between charcoal properties

| | **Moisture Content** | **Friability** | **Bulk Density** | **Calorific Value** | **Volatile Matters** | **Ash Content** | **Fixed Carbon** |
|---|---|---|---|---|---|---|---|
| **Moisture Content** | X | | | | | | |
| **Friability** | **.72**** | X | | | | | |
| **Bulk Density** | -.24 | -.36 | X | | | | |
| **Calorific Value** | **.45*** | -.01 | -.02 | X | | | |
| **Volatile Matters** | -.34 | -.22 | .14 | -.21 | X | | |
| **Ash Content** | **.46*** | -.13 | **.37*** | .05 | -.30 | X | |
| **Fixed Carbon** | .27 | .26 | -.21 | .21 | **-.99**** | .13 | X |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | | |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | |

From the **table 4.8** of correlations, moisture content of charcoal is significantly influencing friability @0.01 level and its calorific value and ash content are also significantly affecting @0.05 level of confidence. This shows that higher moisture content in charcoal is higher friability, calorific value and ash content. On the other hand, the higher bulk density of charcoal means the more ash content @0.01 level and *vice versa*. In the meanwhile, highly significance is revealed in volatile matters with fixed carbon which is negatively influence to each other.

### 4.2.9 Physico-chemical properties of wood used for charcoal production

### 4.2.10 Calorific Value (MJ/Kg)

Highly significant difference ($P<0.05$) was found to exist among the tree species studied with respect to calorific value of wood. However the at par groups observed were among *C. tribuloides, Q. helferiana and S. wallichii*, among *C. tribuloides, Q. helferiana and B. variegata*, among *Q. helferiana*, *L. dealbatus*, *L. pachyphyllus* and *B. variegata*, *L. pachyphyllus, L. dealbatus* and *W. grandis* and between *L. polystachyus* and *W. grandis.* Maximum calorific value recorded in *L. polystachyus* and minimum was found in *S. wallichii* (**Table 4.9**).

### 4.2.11 Ash content (%)

The analysis of ash content of tree wood revealed that highly significance difference among the charcoal wood species studied with maximum ash content (3.02%) in *Q. helferiana* and minimum ash content (0.75%) in *L. polystachyus (***Table 4.9)**. Non significant groups observed were: among *C. tribuloides*, *S. wallichii*, *L. pachyphyllus, L. polystachyus* and *L. dealbatus*, among *C. tribuloides*, *S. wallichii*, *L. pachyphyllus*, *L. dealbatus* and *W. grandis*, among *S. wallichii*, *L. pachyphyllus*, *B. variegata* and *W. grandis* and between *Q. helferiana* and *B. variegata*. Rest of the combinations was significant with each other.

### 4.2.12 Carbon content (%)

Carbon content of wood sample of the species studied has shown highly significant variations among them, however, the non significant groups were observed between *Q. helferiana* and *B. variegata*, among *C. tribuloides*, *S. wallichii*, *L. pachyphyllus*, *L. dealbatus* and *W. grandis*, among *S. wallichii*, *L. pachyphyllus, L. polystachyus, L. dealbatus* and *C. tribuloides*. Maximum carbon content was in the wood sample of *L. polystachyus* (45.97%) and the minimum was found in *Q. helferiana* (43.7%) (**Table 4.9)**.

### 4.2.13 Density ($g/cm^3$)

The density of the wood samples studied ranged from 0.521 $g/cm^3$ (*L. dealbatus*) to 0.703 $g/cm^3$ *(L. polystachyus*) (**Table 4.9)**. Species were observed to be significantly differed with respect to wood density except few at par groups. The at par groups observed with respect to wood density were: between *B. variegata* and *W. grandis*, among *C. tribuloides*, *Q. helferiana* and *L. pachyphyllus*, between *C. tribuloides* and *L. pachyphyllus* and among *C. tribuloides*, *S. wallichii* and *L. polystachyus*.

### 4.2.14 Moisture content (%)

Moisture content in wood samples studied seemed to vary significantly ($P<0.05$). The ranged was from 36.7% in *L. dealbatus* to 55.75% in *L. polystachyus* (**Table 4.9**). However, the difference in moisture content was found to be non significant among *C. tribuloides, Q. helferiana* and *S. wallichii,* and among *L. pachyphyllus, B. variegata* and *W. grandis*.

### 4.2.15 Comparative analysis of charcoal properties and properties of the wood samples of the respective tree species

A comparison between few physico-chemical properties of the charcoal samples and their respective wood samples revealed that moisture content, calorific value and carbon content were remarkably higher in charcoal samples compared to the respective wood samples among all the selected tree species (**Figure 4.15, 4.16. 4.17**). However, in *E. officinalis* and *S. wallichii* carbonization seemed to reduce the ash content (**Fig. 4.18**).

**Table 4.9:** Physico-chemical properties of wood used for charcoal production

| Species | Cal. Value (MJ/Kg) | Ash Content (%) | Carbon Content (%) | Density ($g/cm^3$) | Moisture Content (%) |
|---|---|---|---|---|---|
| *C. tribuloides* | $16.4^{ab}$ | $1.25^{ab}$ | $45.47^{cd}$ | $0.681^{de}$ | $48.79^{c}$ |
| *Q. helferiana* | $16.54^{abc}$ | $3.02^{d}$ | $43.7^{a}$ | $0.64^{c}$ | $50.97^{c}$ |
| *S. wallichii* | $16.2^{a}$ | $1.28^{abc}$ | $45.44^{cd}$ | $0.676^{de}$ | $49.91^{c}$ |
| *L. pachyphyllus* | $16.76^{cd}$ | $1.27^{abc}$ | $45.45^{cd}$ | $0.666^{cd}$ | $38.31^{ab}$ |
| *L. polystachyus* | $17.16^{e}$ | $0.75^{a}$ | $45.97^{d}$ | $0.703^{e}$ | $55.75^{d}$ |
| *L. dealbatus* | $16.78^{cd}$ | $1.12^{ab}$ | $45.6^{cd}$ | $0.521^{a}$ | $36.7^{a}$ |
| *B. variegata* | $16.66^{bc}$ | $2.4^{cd}$ | $44.32^{ab}$ | $0.602^{b}$ | $40.22^{b}$ |
| *W. grandis* | $17.113^{de}$ | $1.84^{bc}$ | $44.88^{bc}$ | $0.597^{b}$ | $39.57^{b}$ |
| **$SE_m$** | 0.167 | 0.465 | 0.465 | 0.014 | 1.233 |
| **$CD_{0.05}$** | 0.355** | 0.987** | 0.987** | 0.030** | 2.613** |
| **$CD_{0.01}$** | 0.489 | 1.359 | 1.359 | 0.042 | 3.601 |

Values with similar letters among the species are not significantly different at $P < 0.05$.

**Table 4.10:** Pearson's correlation between wood properties

| | Moisture Content | Calorific Value | Ash Content | Carbon Content |
|---|---|---|---|---|
| Moisture Content | X | | | |
| Calorific Value | -.14 | X | | |
| Ash Content | -.03 | -.30 | X | |
| Carbon content | .03 | .30 | **-1.00**** | X |
| **. Correlation is significant at the 0.01 level (2-tailed) | | | | |

As in the case of wood properties, the study found that ash content and carbon content of wood is significantly negatively correlated (@0.01). Those woods, which have more ash content, possess less carbon content and *vice versa* (**Table 4.10**).

**Table 4.11:** Pearson's correlation between wood and charcoal properties

| | Wood Moisture Content | Wood Calorific Value | Wood Ash content | Wood Carbon content |
|---|---|---|---|---|
| Charcoal Moisture Content | -.22 | -.28 | .08 | -.08 |
| Charcoal Calorific Value | -.22 | **-.43*** | -.21 | .21 |
| Charcoal Ash Content | .30 | -.10 | .35 | -.35 |
| Charcoal Carbon content | **.52**** | **-.64**** | .13 | -.13 |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | |

Wood properties and its converted charcoal properties reveals that the wood moisture and carbon content were found to be highly correlated with each other (**Table 4.11**). Woods having more moisture contain more carbon in charcoal and more carbon in charcoal means more moisture in its wood state. However, calorific value is interrelated as significantly affected to charcoal and wood showing that less calorific value of wood and more calorific value in its charcoal form and *vice versa*, this is because that more amount of carbons, volatile matters and lignin contents in wood were removed during the process of pyrolysis, thus more components were removed, resulting to less calorific value. Also negative siginificant correlation is found between wood calorific value and charcoal carbon content.

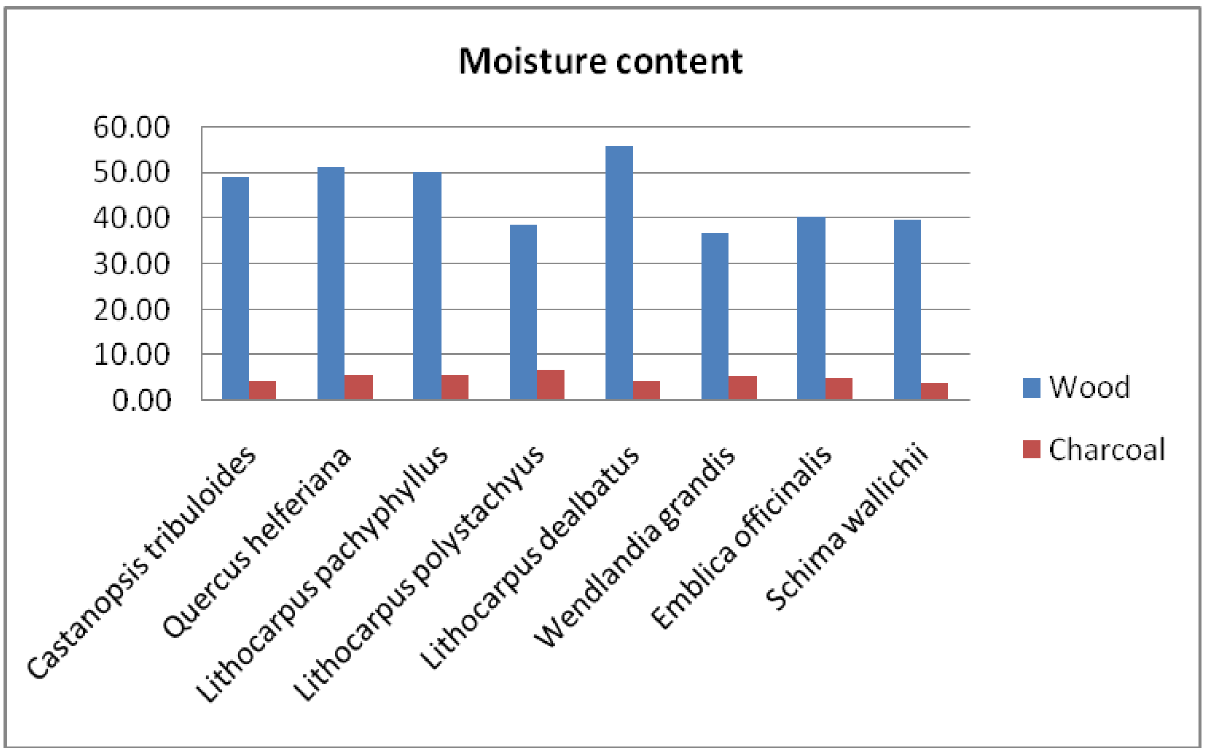



**Figure 4.15:** Moisture content in wood and charcoal (%)

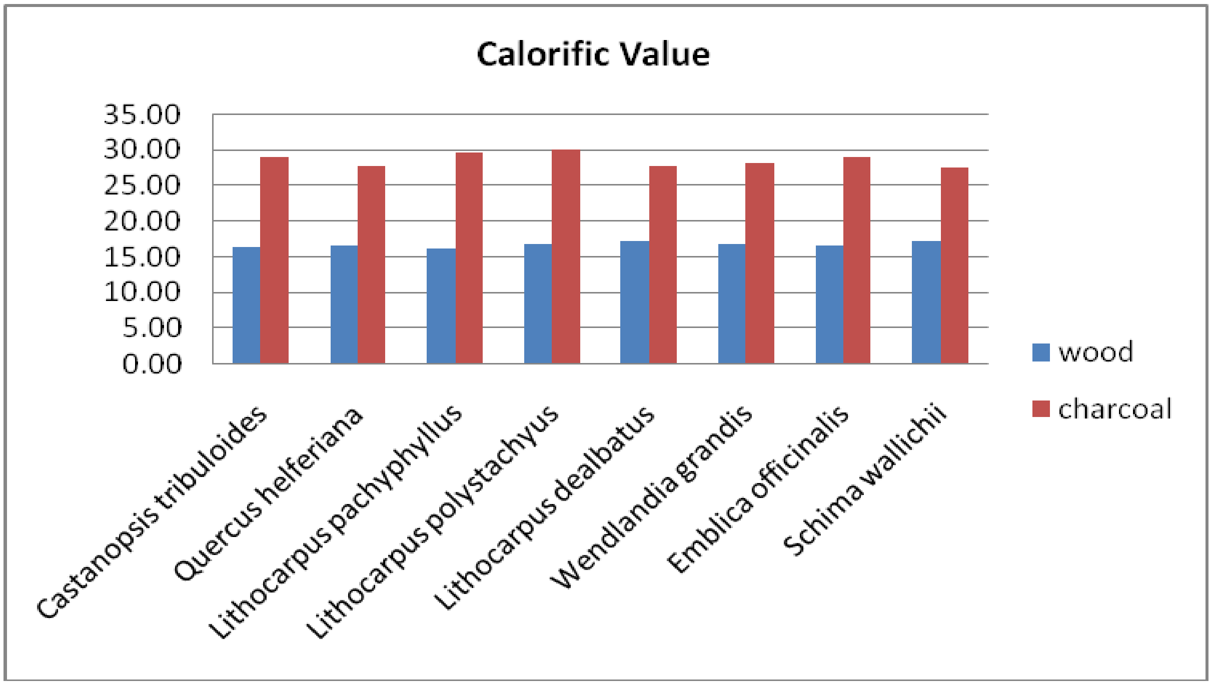



**Figure 4.16:** Calorific value in wood and charcoal (MJ/Kg)

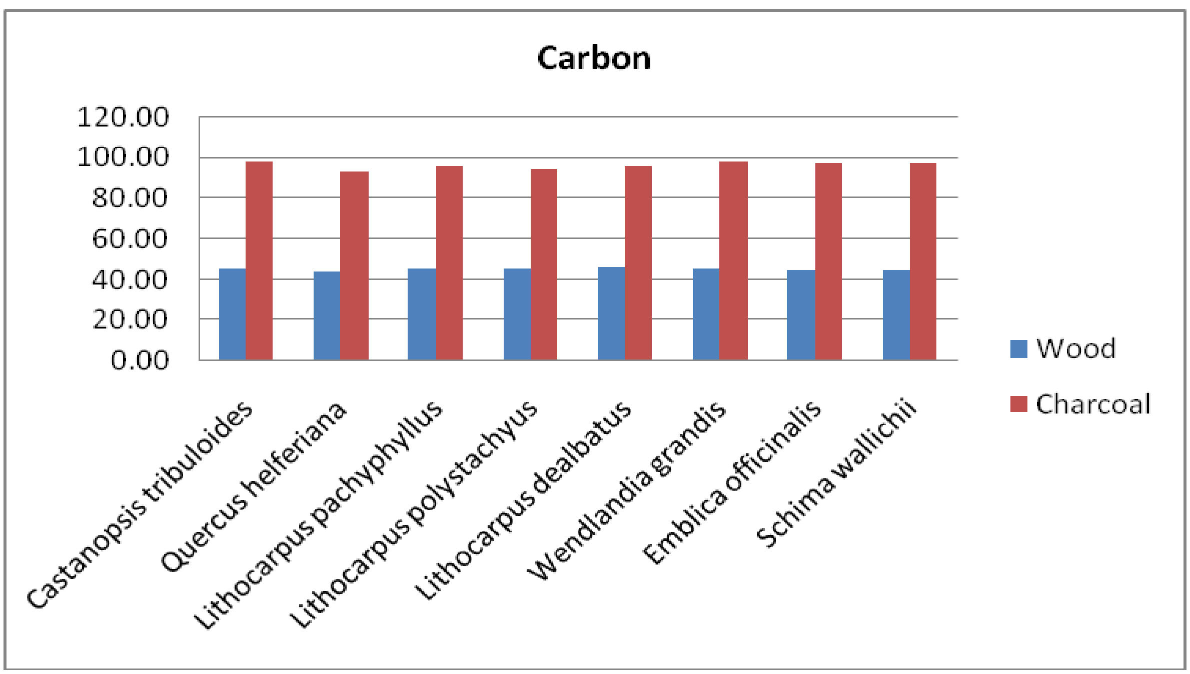



**Figure 4.17:** Carbon content in wood and charcoal (%)

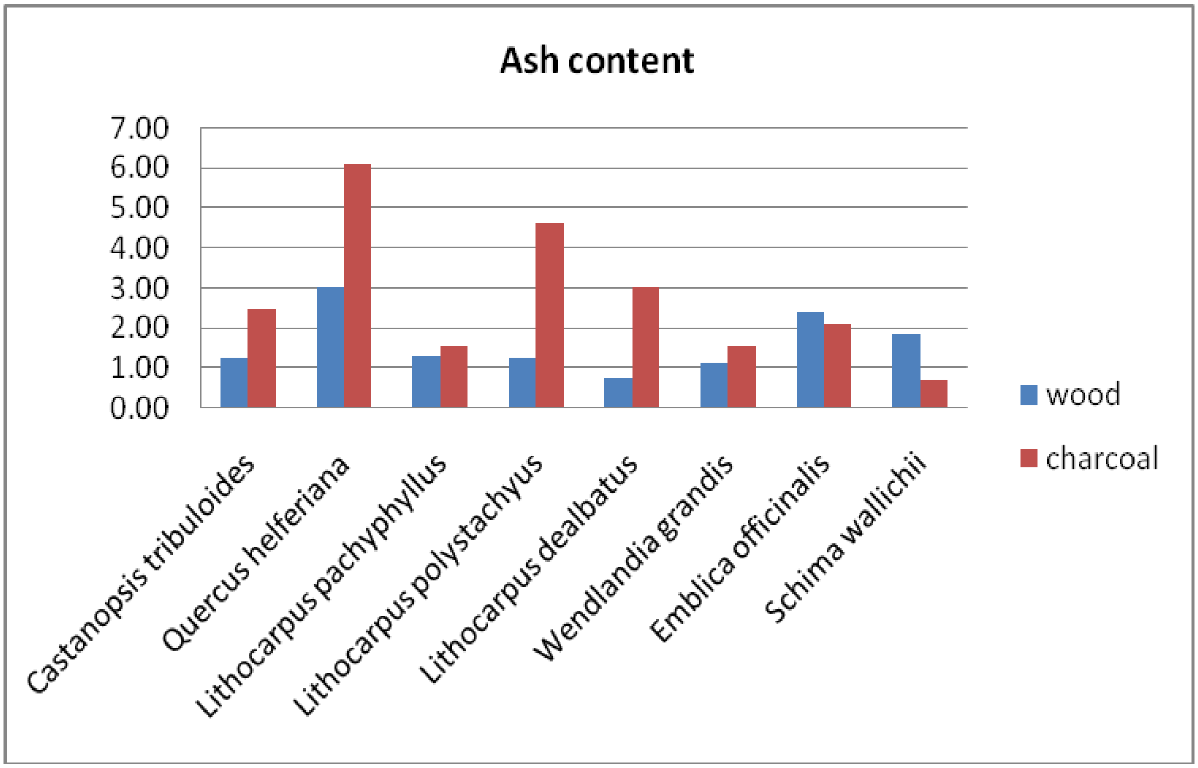



**Figure 4.18:** Ash content in wood and charcoal (%)

### 4.2.16 Conversion efficiency

From the observation it was found that the methods employed for producing charcoal were the traditional kiln and pit method. It is revealed from the experiment of wood-to-charcoal conversion in air dried raw material, that the conversion efficiency was 22% in kiln method and 16% in pit method (**Table 4.12**). Comparing the efficiency with other methods from other countries, it can be concluded that the present methods of charcoal production in Mizoram are significantly less efficient.

**Table 4.12:** Conversion efficiencies of different charcoal production methods

| Method | Conversion efficiency on air dry basis (%) | Source |
|---|---|---|
| Steel kiln | 27-35 | Giz Hera Cooking Energy Compendium (2018) |
| Brick kiln | 30 | Giz Hera Cooking Energy Compendium (2018) |
| Casamance | 31 | Giz Hera Cooking Energy Compendium (2018) |
| Traditional kiln | 22 | Present observation |
| Traditional Pit | 16 | Present observation |

### 4.2.17 Preferred and non-preferred charcoal qualities

By following the standard desireable qualities of charcoal laid out by FAO (1983), the study species were classified according to their standard scores based on different parameters. The standard score was fixed at 5 point taking mean as 5 and standard deviation as 1. Each species was given their respective scores for the different qualities resulted from the observations, and subsequently the graphical representative was made in order to evaluate each species scores for their respective preferrable (**Fig. 4.19**) and non-preferrable qualities.

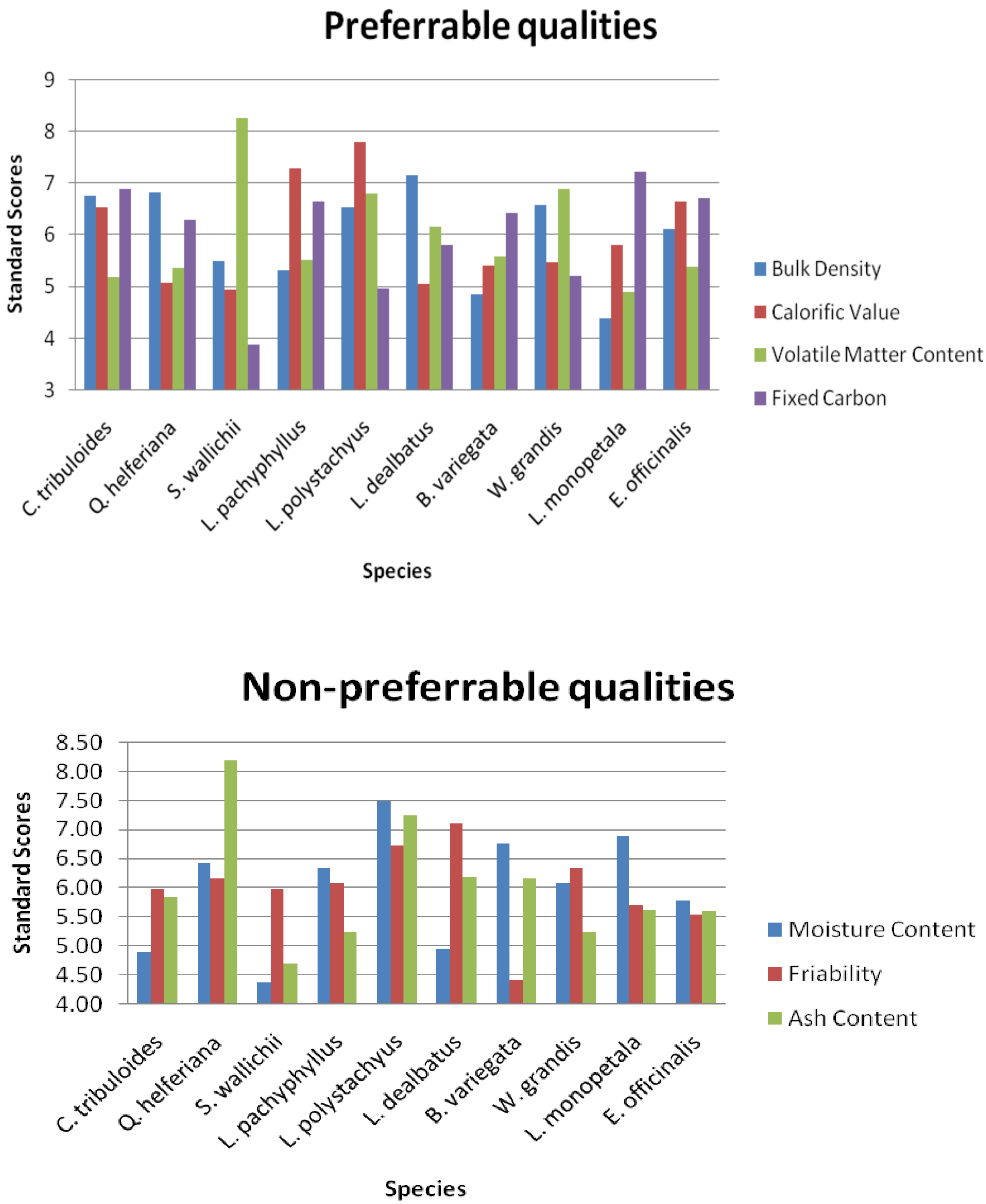



**Figure 4.19:** Preferred and non-preferred charcoal qualities represented in terms of standard scores (FAO, 1983)

### 4.2.18 Relative scores for charcoal qualities preferred species

From the standard scores generated in **Fig. 4.19**, positive scores i.e. the number of preferable quality above 5 scale for each of the selected species were listed. Similarly the negative scores having non preferrable qualities for each species were also listed out in tabular form (**Table 4.13**). The relative scores for each species were calculated and accordingly the selected species were ranked. The observed rank for each species was then compared with the respondents ranking. The study thus revealed that the tree species of *L. dealbatus* ranked the highest in both the cases. It was also found that the relative score for the other high ranking species such as *L. polystachyus, Q. helferiana, L. pachyphyllus* and *C. tribuloides* were also matching with the ranking order of respondents.

**Table 4.13:** Relative scores for quality traits of charcoal in different species and their ranking.

| Species | Preferrable qualities (A) | Non-preferrable qualities (B) | Sum A+B | Ranking based on quality | Respondents ranking |
|---|---|---|---|---|---|
| *C. tribuloides* | 3 | -2 | 1 | 2 | 5 |
| *Q. helferiana* | 4 | -3 | 1 | 2 | 3 |
| *S. wallichii* | 2 | -1 | 1 | 2 | 6 |
| *L. pachyphyllus* | 4 | -3 | 1 | 2 | 4 |
| *L. polystachyus* | 4 | -3 | 1 | 2 | 2 |
| *L. dealbatus* | 4 | -2 | 2 | 1 | 1 |
| *B. variegata* | 3 | -2 | 1 | 2 | 7 |
| *W. grandis* | 4 | -3 | 1 | 2 | 8 |
| *L. monopetala* | 3 | -3 | 0 | 3 | 9 |
| *E. officinalis* | 4 | -3 | 1 | 2 | 10 |

## 4.3 The impact of charcoal production on environment

### 4.3.1 Status of raw materials

From the survey conducted (n=200), most of the respondents (67.5%) felt that the availability of raw materials drastically reduced as compared to the previous years (**Figure 4.20**). On the other hand, those villages especially situated near forest protected areas seemed to feel no change in availability of resources (32.5%). It was observed that most of the villages were facing the problem of declining tree species since the rotation period of the fallow land become shorter due to limited area of arable land around their respective villages.

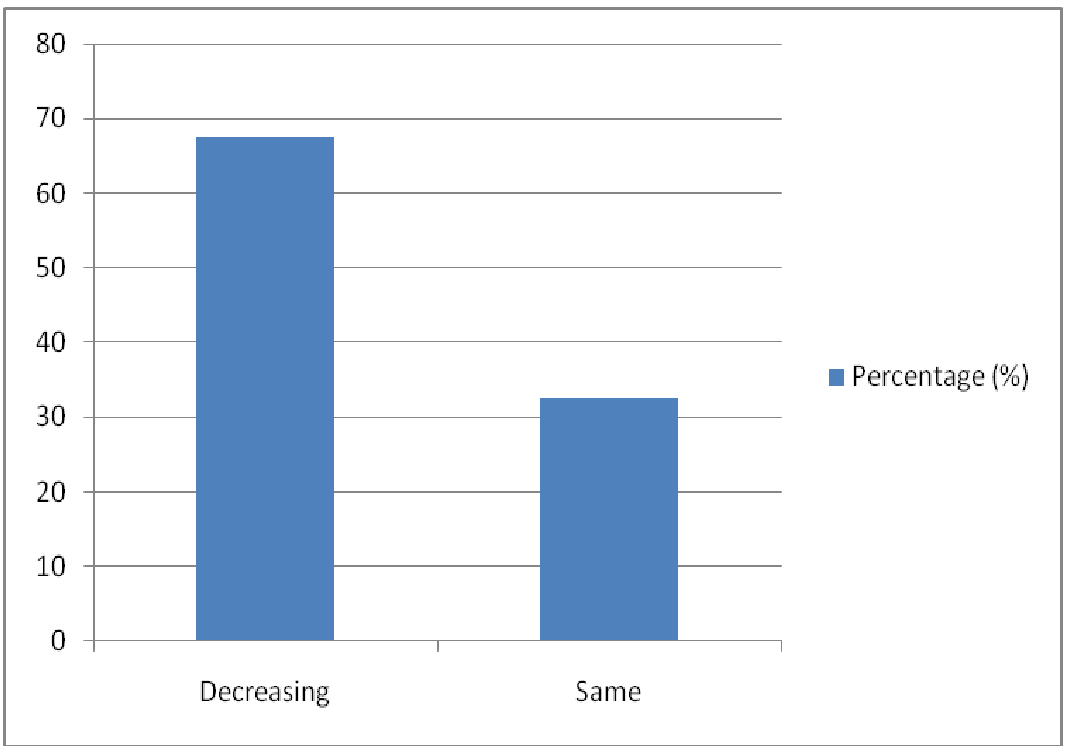



**Figure 4.20:** Status of availability of raw materials from previous years

### 4.3.2 Impact of charcoal production and utilization on public health indicators

There are some report of adverse effects on human health while producing and using charcoal due to continuous exposure to smoke, gas and heat. However, from the survey it was revealed that, 46% of the total respondents had complaints about physical injury such as back ache, sore hands, burns, cuts and other minor injuries while working in charcoal production, whereas 13% stressed about general sickness in the form of general exhaustion, chest pain, cough, slight respiratory problems, eyes tearing, etc. On the other hand, about 41% of those who were engaged on regular charcoal production and consumption did not have any complaint (**Fig. 4.21**).

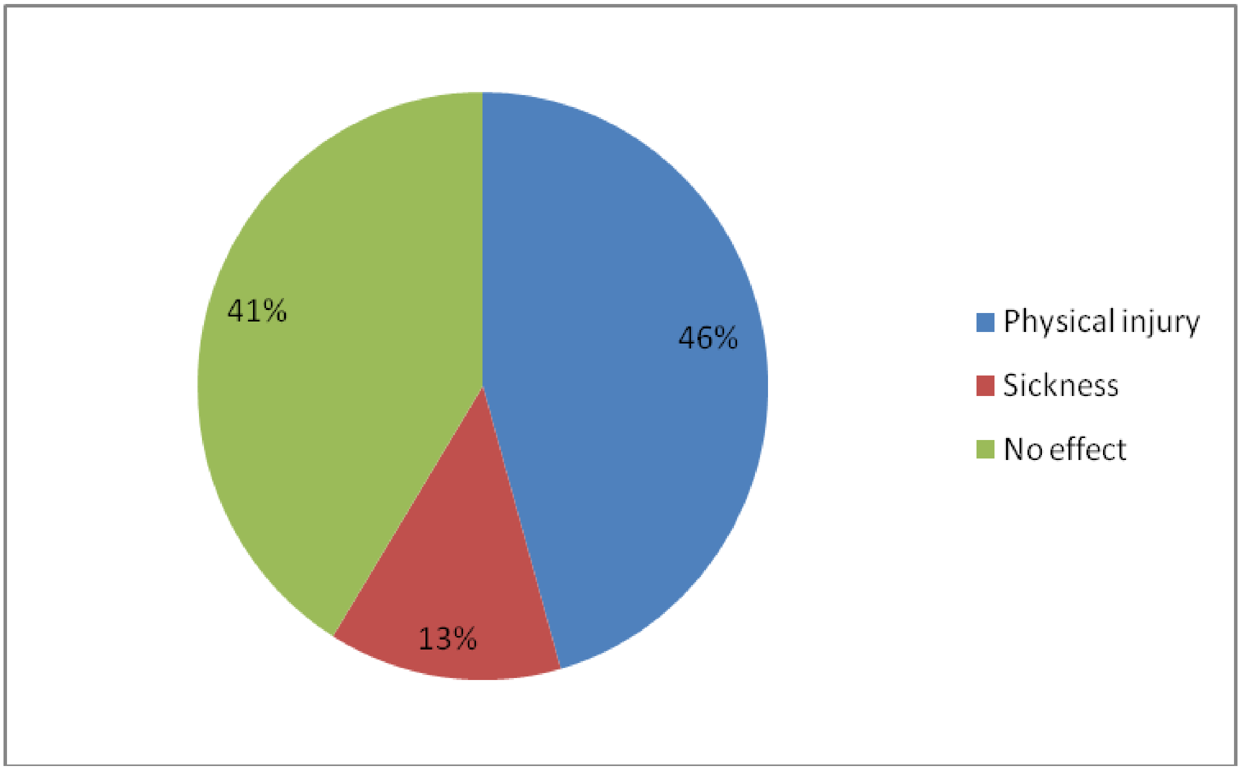



**Figure 4.21:** Public health indicators (producers and consumers)

### 4.3.3 Impact on soil physico-chemical properties

**Physical properties of soil**

**Bulk Density (g/cm$^3$)**

Bulk density of soil was marginally but non-significantly decreased in charcoal production areas when compared with adjoining areas (**Table 4.14A**) under both the methods of charcoal production. A non-significant effect of site of collection of soil on soil bulk density was observed. While comparing methods of charcoal production it was found that pit method had significantly less bulk density (1.288 g/cm$^3$) than kiln method (1.324 g/cm$^3$). The interaction between site of soil sample collection and method of charcoal production followed had no effect over soil bulk density.

**Water Holding Capacity (%)**

Water Holding Capacity of soil was varying significantly between the soil samples collected from charcoal production areas and adjoining areas. The charcoal production areas had significantly higher water holding capacity of the soil compared to soils of adjoining areas under both the methods of charcoal production. Method of charcoal production had significant effect on water holding capacity of soil with more water holding capacity with pit method (65.903%) than kiln method (58.29%) (**Table 4.14A**). Interaction between site of soil sample collection and method of charcoal production has no effect on water holding capacity of the soil.

**Clay content (%)**

Sand, silt and clay composition is the fundamental property of a particular soil regulating soil texture. However, charcoal production process had changed soil clay (finer) composition, the quantum of which was further varying with the method of charcoal production. Both kiln and pit methods have increased finer matter composition in charcoal production areas than adjoining areas. Effect of sampling site (charcoal production area and adjoining area), charcoal production method (kiln method and pit method) and the interaction of sampling site for soil collection and method of charcoal production on soil finer matter (clay) composition remained highly significant. Pit method had more clay/ finer matter (14.75%) than kiln method (11.423%) (**Table 4.14B).**

**Silt content (%)**

There was non-significant effect of sampling site (between charcoal production area and adjoining area) on silt content of soil but a highly significant effect of method of charcoal production (between pit and kiln methods) on silt content of soil was found. The interaction effect between site of soil collection and method of charcoal production had non-significant effect on soil silt composition. In all the cases, charcoal production area had higher soil silt content than its respective adjoining sites. Pit method had higher soil silt matter content (11.25%) than its respective kiln method (10.667%) (**Table 4.14B)**.

**Sand content (%)**

Charcoal production process not only mechanizes the wood, at the same time it attacks the sub-soil rocks to imbibe the weathering process to go faster as well. Highly significant variation was observed between 2 sites (charcoal production area and adjoining area), between 2 methods (kiln and pit methods of charcoal production) with respect to sand composition of soil. Their interaction (interaction between 2 sites of soil collection and 2 methods of charcoal production) also exhibited highly significant variation on sand matter content of soil. Interestingly, it was of record that pit method had decreased sand content of soil in charcoal production area than respective adjoining area but the reverse trend was observed with kiln method on an average. Sand composition from soil collected from kiln method of charcoal production was 77.91% and that from pit method of charcoal production was 74.0% (**Table 4.14B)**.

## Chemical properties of soil

### Carbon content (%)

The analysis of soil samples from charcoal production area and adjacent area followed through both kiln and pit methods revealed that pit method provides significantly more soil carbon (0.703%) compared to its respective kiln counterpart (0.507%) (**Table 4.15A)**. On the other hand, taking soil samples from charcoal production area and adjacent area it has been found significantly more carbon content in adjacent area irrespective of method of charcoal production. Interaction of production method and soil sampling site has no effect (non significant) on soil carbon content i.e. the effect of method of charcoal production on soil carbon content and nearness or remoteness of soil sampling from charcoal production area on soil carbon content are very much independent of each other. Soil carbon content of kiln and pit carbon production area never interfered by sampling from nearer or away from charcoal production area and the vice versa too observed on soil carbon concentration.

### Nitrogen (%)

The soil nitrogen content as indicator for plant growth and rhizosphere interaction was varying significantly with distance of sampling from charcoal production area. It is ironical to record significant variation of nitrogen content of soil between charcoal production area and the adjacent area, however, their order was not uniform depending on method of charcoal production; pit method reduced soil nitrogen at charcoal production area than adjacent area but the reverse trend in case of kiln method was observed. While comparing both the methods, pit method became nitrogen enriching than kiln method, both were having their respective soil nitrogen values to be 0.389% and 0.351% (**Table 4.15A)**. Charcoal production method not only affected soil nitrogen content but also the quantum of effect was dependent on place of sample collection whether at charcoal production area or adjoining area thus significant interaction effect between method of charcoal production and site of soil sample collection was found.

**Available Phosphorus (mg/kg)**

Significant relation was observed between charcoal production area and adjoining area with respect to phosphorus content of soil. Interestingly, both the charcoal production methods had recorded higher soil phosphorus content in their respective charcoal production areas than their adjoining sites. Method of charcoal production had highly significant effect on soil phosphorus content. Pit method had higher soil phosphorus (1.934 mg/kg than kiln method (1.585 mg/kg) (**Table 4.15A)**. Interaction between method of charcoal production and site of soil collection (from charcoal production area or adjoining area) was having non-significant effect on soil phosphorus content. It signifies the effect of method of charcoal production on soil phosphorus concentration is very much independent of nearness or distance of soil sampling and the *vice versa* also true.

**Magnesium (cmol/kg)**

Magnesium content of soil varied non-significantly based on sampling site (nearer or farther from charcoal production), significantly varying between 2 methods (between kiln and pit methods) and non-significantly between their interactions (sites and methods). More soil Mg content (0.212 cmol/kg) was observed with Kiln method compared to its pit counterpart (0.199 cmol/kg) (**Table 4.15B)**. In all the methods it was observed that Mg content of soil was higher in charcoal production area than adjoining area for both the methods of charcoal production namely kiln and pit methods. Interaction study between soil sampling sites (at charcoal production area or adjoining areas) and methods of charcoal production (kiln and pit methods) means the effect of soil Mg content is not only dependent on method of charcoal but independent of site we are sampling nearer or farther to charcoal production area.

**Sodium (cmol/kg)**

The concentration of Na in soil was observed to be non-significantly varying with site of soil sample collection (charcoal production area or adjoining area), method of charcoal production (kiln or pit method) and their interaction as well. However, pit method provided more Na of soil (0.059 cmol/kg) than its kiln counterpart (0.047 cmol/kg) (**Table 4.15B)**. Though the reverse trend has been observed for Ca and Mg of soil, charcoal production area compared with adjoining area had more Na content of soil under both the methods of charcoal production.

**Potassium (cmol/kg)**

Potassium content of soil did not change significantly by charcoal production. Table (**Table 4.15B)**. Further stated that neither site of collection of soil sample (from charcoal production area or adjoining area), the method of charcoal production (by kiln or peat method) nor their interaction have any significant effect over concentration of soil K. There was marginal difference of soil K concentration between kiln method (0.225 cmol/kg) and pit method (0.206 cmol/kg). Further, less soil K content in charcoal production area is observed than the adjoining area under both the types of charcoal production.

**Calcium (cmol/kg)**

Calcium content of soil was observed to be non- significant when compared soils under both the methods of charcoal production, compared soil samples from charcoal production area and their interaction. Kiln method provided better calcium accumulation (0.167 cmol/kg) than pit method (0.082 cmol/kg) (**Table 4.15C)**. However, charcoal production area provided more calcium concentration in soil than adjacent area in both the methods of charcoal production.

**Cation Exchange Capacity (cmol/kg**)

The site of collection between charcoal production areas and adjoining areas had non-significant effect over cation exchange capacity of soil. Method of charcoal production had significant effect on cation exchange capacity of soil but the interaction between method of charcoal production and site of soil sample collection (charcoal production area and adjoining area) had non-significant effect on cation exchange capacity of soil. Kiln method had more CEC of soil (1.123 cmol/kg) than its pit counterpart (1.102 cmol/kg) (**Table 4.15C)**. Soil sample from charcoal production areas gave more CEC than the adjoining area under both the methods of charcoal production.

**Electrical Conductivity (dS/m)**

Electrical conductivity of soil was not found to be remarkably varying between charcoal production area and adjoining area though higher values was with charcoal production area than adjoining area under both pit and kiln methods of charcoal production. The method of charcoal production had significant effect on electrical conductivity of soil. The interaction between site of soil collection (charcoal production area and adjoining area) and method of charcoal production (kiln and pit method) had non-significant effect. Soil collected areas with Pit method had shown more electrical conductivity (0.3675 dS/m) than the soil under kiln method of charcoal production (0.3315 dS/m) **(Table 4.15C**).

**Soil pH**

Soil pH is a very important limiting factor for crop production under Mizoram condition the prevailing soil being acidic. **Table 4.15D** revealed that charcoal production has increased soil pH under both the methods of charcoal production and had reduced soil acidity. Statistical analysis opines that there was highly significant variation of pH of soil when compared between charcoal production area and adjoining area, between pit method and kiln method of charcoal production and significant variation among the interactions of 2 sites and 2 methods. Kiln method has shown more pH (5.334) compared to its pit counterpart (4.798) (**Table 4.15D)**. Consequently former became more farmers' friendly for acid soil reclamation. On the other hand, charcoal production area has more pH than adjoining area under both the cases of charcoal production.

**Exchangeable Acidity (cmol/kg)**

Charcoal production process on an average increases exchangeable acidity from soil as evident from **Table 4.15D**. There was further record from soil analysis made that significant difference between exchangeable soil acidity content between 2 sampling sites namely, charcoal production area and adjoining area, more exchangeable acid under charcoal production area both under kiln and pit methods of charcoal production. Comparing both the methods of charcoal production pit method posed significantly higher exchangeable acidity in soil (0.556 cmol/kg) than its kiln counterpart (0.472 cmol/kg). The interaction between method of charcoal production and site of sample collection (charcoal production area or adjoining area) has non-significant effect over soil exchangeable acidity.

**Table 4.14A:** Effect of method of charcoal production and site of sampling on soil physical properties

| | **Bulk Density (g/cm$^3$)** | | | **WHC (%)** | | |
|---|---|---|---|---|---|---|
| | **Kiln** | **Pit** | | **Kiln** | **Pit** | |
| **CA** | 1.285 | 1.24 | | 59.702 | 67.285 | |
| **AA** | 1.363 | 1.337 | | 56.878 | 64.521 | |
| **Mean** | 1.324 | 1.288 | | 58.29 | 65.903 | |
| **Comparison** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** |
| **$SE_m$** | 0.039 | 0.039 | 0.055 | 1.341 | 1.341 | 1.897 |
| **$CD_{0.05}$** | NS | 0.078* | NS | 2.710** | 2.710* | NS |
| **$CD_{0.01}$** | NS | 0.105 | NS | 3.621 | 3.621 | NS |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.14B:** Effect of method of charcoal production and site of sampling on soil physical properties

| | Clay (%) | | Silt (%) | | Sand (%) | |
|---|---|---|---|---|---|---|
| | **Kiln** | **Pit** | **Kiln** | **Pit** | **Kiln** | **Pit** |
| **CA** | 15.046 | 15.4 | 12.374 | 12 | 72.58 | 72.6 |
| **AA** | 7.8 | 14.1 | 8.96 | 10.5 | 83.24 | 75.4 |
| **Mean** | 11.423 | 14.75 | 10.667 | 11.25 | 77.91 | 74 |

| | Clay (%) | | | Silt (%) | | | Sand (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Comparison** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** |
| **$SE_m$** | 0.710 | 0.710 | 1.003 | 0.562 | 0.562 | 0.795 | 1.013 | 1.013 | 1.433 |
| **$CD_{0.05}$** | 1.434** | 1.434** | 2.028** | NS | 1.137** | NS | 2.048** | 2.048** | 2.897** |
| **$CD_{0.01}$** | 1.916 | 1.916 | 2.709 | NS | 1.519 | NS | 2.736 | 2.736 | 3.870 |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.15A:** Effect of method of charcoal production and site of sampling on soil chemical properties

| | Carbon (%) | | Nitrogen (%) | | AVP (mg/kg) | |
|---|---|---|---|---|---|---|
| | **Kiln** | **Pit** | **Kiln** | **Pit** | **Kiln** | **Pit** |
| **CA** | 0.470 | 0.648 | 0.370 | 0.367 | 1.872 | 2.160 |
| **AA** | 0.544 | 0.757 | 0.332 | 0.411 | 1.299 | 1.709 |
| **Mean** | 0.507 | 0.703 | 0.351 | 0.389 | 1.585 | 1.934 |

| **Comparison** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** |
|---|---|---|---|---|---|---|---|---|---|
| **$SE_m$** | 0.041 | 0.041 | 0.058 | 0.019 | 0.019 | 0.027 | 0.152 | 0.152 | 0.215 |
| **$CD_{0.05}$** | 0.095** | 0.095* | NS | 0.044* | NS | 0.062* | 0.307* | 0.307** | NS |
| **$CD_{0.01}$** | 0.139 | 0.139 | NS | 0.064 | NS | 0.091 | 0.410 | 0.410 | NS |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.15B:** Effect of method of charcoal production and site of sampling on soil chemical properties

| | Mg (cmol/kg) | | | Na (cmol/kg) | | | K (cmol/kg) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Kiln | Pit | | Kiln | Pit | | Kiln | Pit | |
| CA | 0.268 | 0.301 | | 0.051 | 0.073 | | 0.263 | 0.258 | |
| AA | 0.156 | 0.098 | | 0.043 | 0.045 | | 0.188 | 0.154 | |
| Mean | 0.212 | 0.199 | | 0.047 | 0.059 | | 0.225 | 0.206 | |
| **Comparison** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** |
| $SE_m$ | 0.057 | 0.057 | 0.081 | 0.019 | 0.019 | 0.027 | 0.053 | 0.053 | 0.075 |
| $CD_{0.05}$ | NS | 0.132* | NS | NS | NS | NS | NS | NS | NS |
| $CD_{0.01}$ | NS | 0.192 | NS | NS | NS | NS | NS | NS | NS |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.15C:** Effect of method of charcoal production and site of sampling on soil chemical properties

| | Calcium (cmol/kg) | | CEC (cmol/kg) | | EC (dS/m) | |
|---|---|---|---|---|---|---|
| | Kiln | Pit | Kiln | Pit | Kiln | Pit |
| **CA** | 0.179 | 0.090 | 1.268 | 1.285 | 0.242 | 0.319 |
| **AA** | 0.155 | 0.074 | 0.978 | 0.920 | 0.421 | 0.416 |
| **Mean** | 0.167 | 0.082 | 1.123 | 1.102 | 0.331 | 0.367 |

| Comparison | Site (S) | Method (M) | S X M | Site (S) | Method (M) | S X M | Site (S) | Method (M) | S X M |
|---|---|---|---|---|---|---|---|---|---|
| **$SE_m$** | 0.064 | 0.064 | 0.091 | 0.155 | 0.155 | 0.219 | 0.055 | 0.055 | 0.077 |
| **$CD_{0.05}$** | NS | NS | NS | NS | 0.358* | NS | NS | 0.111* | NS |
| **$CD_{0.01}$** | NS | NS | NS | NS | 0.520 | NS | NS | 0.148 | NS |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.15D:** Effect of method of charcoal production and site of sampling on soil chemical properties

| | Exchangeable Acidity (cmol/kg) | | | pH | | |
|---|---|---|---|---|---|---|
| | Kiln | Pit | | Kiln | Pit | |
| **CA** | 0.508 | 0.564 | | 5.721 | 4.929 | |
| **AA** | 0.436 | 0.549 | | 4.948 | 4.668 | |
| **Mean** | 0.472 | 0.556 | | 5.334 | 4.798 | |
| **Comparison** | **Site (S)** | **Method (M)** | **S X M** | **Site (S)** | **Method (M)** | **S X M** |
| **$SE_m$** | 0.021 | 0.021 | 0.030 | 0.117 | 0.117 | 0.166 |
| **$CD_{0.05}$** | 0.049* | 0.049* | NS | 0.237** | 0.237** | 0.335* |
| **$CD_{0.01}$** | 0.071 | 0.071 | NS | 0.316 | 0.316 | 0.447 |

CA – Charcoal (Production) area; AA – Adjacent area

**Table 4.16:** Pearson's correlation between soil physical properties in charcoal production sites

| | **Clay** | **Silt** | **Sand** | **Bulk Density** | **WHC** |
|---|---|---|---|---|---|
| **Clay** | X | | | | |
| **Silt** | **.586**** | X | | | |
| **Sand** | **-.944**** | **-.820**** | X | | |
| **Bulk Density** | -.250 | **-.395*** | **.337*** | X | |
| **WHC** | **.453**** | .242 | **-.418**** | **-.319*** | X |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | |

The correlation within the soil physical properties shows that clay particle is significantly related with silt and water holding capacity, whereas sand is negatively correlated. It is certain that the influence of clay amount is directly affecting silt, sand and water holding capacity. Silt content is also significantly correlated with sand and bulk density in a negative manner. Significant correlation is also found in sand content with bulk density which is positive while WHC is negatively correlated. In the meantime, bulk density is also significant in negative way with WHC of soil.

**Table 4.17:** Pearson's correlation between soil chemical properties in charcoal production sites

| | pH | Electrical Conductivity | AVP | C | N | H | Ca | Mg | Na | K | CEC | Exchangeable Acidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | X | | | | | | | | | | | |
| Electrical Conductivity | .73** | X | | | | | | | | | | |
| AVP | .11 | .04 | X | | | | | | | | | |
| Carbon | -.5* | -.25 | .05 | X | | | | | | | | |
| Nitrogen | -.08 | -.03 | .29 | .60* | X | | | | | | | |
| Hydrogen | -.22 | .08 | .45 | .60* | .61* | X | | | | | | |
| Ca | -.11 | .09 | -.05 | .67** | .59* | .34 | X | | | | | |
| Mg | .25 | .28 | .22 | -.29 | -.30 | .01 | -.48 | X | | | | |
| Na | .28 | .44 | -.01 | .09 | -.13 | .02 | -.10 | .71** | X | | | |
| K | .34 | .37 | .06 | -.21 | -.21 | -.10 | -.33 | .94** | .76** | X | | |
| CEC | .29 | .31 | .03 | -.01 | -.17 | 01 | -.33 | .92** | .72** | .93** | X | |
| Exchangeable Acidity | -.22 | .08 | .45 | .60* | .61* | 1.00** | .34 | .01 | .02 | -.10 | .07 | X |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | | | | | | |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | | | | | | | |

**Table 4.18:** Pearson's correlation between soil physical & chemical properties

| | pH | Electrical Conductivity | AVP | C | N | H | Ca | Mg | Na | K | CEC | Exchangeable Acidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Texture Clay** | .12 | .33 | .42 | .13 | .33 | .71** | .02 | .41 | .25 | .29 | .45 | .71** |
| **Texture Silt** | -.03 | -.04 | .27 | -.14 | -.19 | .13 | -.43 | .46 | .29 | .37 | .48 | .13 |
| **Texture Sand** | -.08 | -.24 | -.42 | -.05 | -.18 | -.58* | .14 | -.48 | -.29 | -.35 | -.52* | -.58* |
| **Bulk Density** | -.23 | -.44 | .45 | -.13 | .08 | .11 | -.03 | -.19 | -.60* | -.31 | -.35 | .11 |
| **WHC** | .23 | .52* | .17 | .32 | .36 | .66** | .24 | .21 | .48 | .15 | .28 | .66** |

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

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

**Table 4.17** shows Correlation between soil chemical properties in charcoal production sites, in which the pH of soil is significantly correlated with electrical conductivity @0.01 while negatively significantly with carbon @0.05. Carbon is significantly correlated with H, N and exchangeable acidity @0.01 while Ca @0.05. N is also significantly correlated with H, Ca and exchangeable acidity @0.01. H is significanty correlated with exachangeable acidity @0.05. Mg is also significantly correlated with Na, K and CEC @0.05. Na is significantly correlated with K and CEC @0.05 and K is also significantly correlated with CEC @0.05.

Correlation between soil physical & chemical properties as facilititates in **Table 4.18** shows that EC is significantly correlated with WHC @0.01. H is significantly correlated with Clay and WHC @0.05 while with sand there is negative significant correlation with sand particles. Na is negtively correlated with bulk density at significant level of 0.01 and so is the correlation of CEC and sand particles. Exhcangeable acidity is significantly correlated with clay and WHC @0.05 whereas with sand it is negative at significant level of 0.01.

**4.3.4. Effect of charcoal production on yield of some agricultural crops**

The polypot experiment conducted to assess the growth and yield of agricultural crops showed that the growth and yield of both bush beans and tomatoes were significanty higher in soils collected from charcoal production sites compared to jhumland and forest soils. In case of bush beans, the result showed significant difference among the treatments; the maximum growth and yield, were recorded in $T_1$, i.e. soil from charcoal production site, except in plant height, number of leaves and the fresh pod weight (**Table 4.19** and **4.20**) wherein an opposite trend was observed. In case of tomato, all the growth and yield parameters were significantly higher ($P<0.05$) in $T_1$ compared to other two treatments (**Table 4.21** and **4.22**). The overall observation revealed that the crops grown in soil collectd from charcoal production sites showed significantly better performance in growth and yield as compared to soils collected form adjacent jhumland and forest areas.

**Table 4.19:** Effect of charcoal production on growth of Bush bean (per plant)

| Treatment | Plant height (cm) | No. of branches | No. of leaves | Leaf Area ($cm^2$) | Total biomass (g) |
|---|---|---|---|---|---|
| **$T_1$** | 31.17 ± 1.81 | 6.72 ± 0.28 | 3.14 ± 0.14 | 66.95 ± 4.72 | 12.61 ± 1.07 |
| **$T_2$** | 31.46 ± 2.88 | 3.86 ± 0.46 | 3.00 ± 0.00 | 27.35 ± 6.21 | 2.16 ± 0.58 |
| **$T_3$** | 24.54 ± 1.33 | 4.00 ± 0.48 | 3.14 ± 0.14 | 36.37 ± 11.93 | 3.39 ± 1.79 |
| **C.D.** | N/A | 1.26 | N/A | 24.64 | 3.74 |
| **$SE_{(m)}$** | 2.11 | 0.42 | 0.12 | 8.23 | 1.25 |

**Table 4.20:** Effect of charcoal production on yield of Bush bean (per plant)

| Treatment | No. of pods | Fresh weight of pods (g) | Dry weight of pods (g) |
|---|---|---|---|
| **$T_1$** | 10.00 ± 1.13 | 37.89 ± 5.12 | 11.6 ± 1.13 |
| **$T_2$** | 4.14 ± 0.26 | 8.40 ± 3.88 | 1.68 ± 0.50 |
| **$T_3$** | 3.71 ± 1.06 | 20.83 ± 17.39 | 2.96 ± 1.76 |
| **C.D.** | 2.72 | N/A | 3.71 |
| **$SE_{(m)}$** | 0.91 | 10.70 | 1.24 |

**Table 4.21:** Effect of charcoal production on growth of Tomato (per plant)

| Treatment | Plant height (cm) | No. of branches | No. of leaves | Leaf area ($cm^2$) |
|---|---|---|---|---|
| **$T_1$** | 55.60 ± 2.44 | 9.25 ± 0.70 | 11.88 ± 0.64 | 49.23 ± 2.41 |
| **$T_2$** | 21.55 ± 3.26 | 6.13 ± 0.48 | 7.38 ± 0.75 | 20.30 ± 2.83 |
| **$T_3$** | 13.19 ± 1.50 | 6.13 ± 0.44 | 8.00 ± 0.66 | 14.81 ± 1.11 |
| **C.D.** | 7.41 | 1.64 | 2.03 | 6.63 |
| **$SE_{(m)}$** | 2.50 | 0.55 | 0.69 | 2.24 |

**Table 4.22:** Effect of charcoal production on yield of Tomato (per plant)

| Treatment | No. of fruits | Average fruit weight (g) | Average fruit size (cm) |
|---|---|---|---|
| **$T_1$** | 10.25 ± 0.90 | 147.15 ± 16.51 | 4.26 ± 0.23 |
| **$T_2$** | 2.25 ± 0.94 | 41.82 ± 10.04 | 3.60 ± 0.20 |
| **$T_3$** | 1.25 ± 0.52 | 11.69 ± 2.18 | 2.83 ± 0.14 |
| **C.D.** | 2.40 | 39.62 | 0.69 |
| **$SE_{(m)}$** | 0.81 | 11.23 | 0.19 |

## Chapter 5

## DISCUSSIONS

### 5.1 Production and Utilization

The charcoal trade in Mizoram is an age long practice by the people, wherein the supply chain starts from the producers to the end users. The producers are those who live in the villages practicing shifting/jhum cultivation and produce charcoal from those trees which are felled during the slash and burn stage. These villages produced charcoal in conjunction to their farming activities which facilitate the supplementary income and meet the emergency cash needs. Charcoal production therefore is a business of choice for the rural poor; it contributes to their household income and provides a safeguard against food-shortages, unemployment and similar poverty-related risks. The major source of materials for charcoal production in the study area is normally from their jhum land, which means that the tree are obtained almost free of cost. In these villages, the land is allotted to each farmer by the Village Council through tenure system. The land tenuring system is well organized that each farmers are allotted to one particular land piece for cultivation; thus, the materials are also collected from their own plot only. Collection of trees from other area within the village land is strictly prohibited by the council. The charcoal production kiln/pit is also constructed within the allotted land itself. In most of the developing world, charcoal makers use traditional means or build temporary earthen kilns for each batch (FAO, 2000). However, it is interesting to note that some producers in Mamit district generate charcoal from own land at the rate of quantity demand by the clients.

From the key informants, it is learnt that production of charcoal on commercial scale was started from two villages in Champhai district, *viz.* Kelkang and Dilkawn. Consequences to the demand of charcoal for different uses from urban and sub-urban areas, other villages also start practicing charcoal production on commercial scale along with their jhum cultivation. The trade was slowly extended to other part of the state and maximum number of production by the villages was observed in the year between 2010 to 2015. Maximum number of charcoal production is represented by Champhai district and Serchhip is next to it. Although there is no identified commercial production in Aizawl and Siaha districts, the demand within these districts are high, which is due to the diverse end uses and lack of conventional energy source as in the case of Siaha district. The charcoals are either directly sold to the retailers or middlemen who are from their respective villages or those from urban and sub-urban areas who either own a vehicle or hire it. Since most of these villages are located in remote areas connected with low grade roads, the charcoal are transported mostly by means of selective vehicles, such as Mahindra pick up, 407 and some other trucks.

Most charcoal coming to city and towns is produced, transported and retailed both legally and illegally. Information from the Forest Department revealed that although there are environmental policies existing in the study area regarding charcoal production, these laws are often flouted especially by commercial transporters. But, these acts are very much tolerated, or occasionally the State Forest department imposes royalty @Rs 30/quintal (1quintal ~ 3bags) at the check gates. The main actors directly involved along the charcoal marketing chains include producers, transporters, middlemen, wholesalers, retailers and consumers. In Aizawl, the charcoal transported to the city through the few gates is delivered to distributors stationed at different corners of the city. Small retailers buy charcoal from distributors; producers are also engaged in retailing charcoal. As the charcoal commodity is moved from the point of production through markets to consumers, it incurs various costs: production, transportation, taxation and other informal costs. Middlemen are involved in the distribution processes, their role and links with the producers and the consumers are also well defined. However, the charcoals are also sold directly to the wholesalers or end users directly by the producers. Charcoal burning and marketing at present requires only minimal financial and human resources. It is mainly consumed within urban and sub-urban areas. Charcoal consumers are normally located in the urban and peri-urban areas and may be divided into two different groups (Sitoe, 2007): i) Domestic - those who use it for cooking and heating the houses and ii) large/industrial consumers - those who use charcoal to cook or generate heat for industrial processes such as collective kitchens (e.g. hospitals, schools, prisons, army base, restaurants and fast food outlets). Since, charcoal is a reliable, convenient and an accessible source of energy at a stable cost when compared to other sources such as electricity, LPG and kerosene (BTG, 2010; Mugo and Ong, 2006), it is therefore, commonly used in the business areas. The survey study findings in Africa by Mutimba and Barasa (2005) reveals that more than 50% of the producers sold their charcoal to vendors *via* transporters as well as directly to households, food businesses and other customers including social institutions. A study in Dar-es-Salaam, United Republic of Tanzania, for example, clearly showed charcoal used in energy-efficient stoves to be the cheapest fuel per unit of energy (Foster, 2000).

The study revealed that the majority of charcoal producing villages were located in the eastern site of the state. Dense wood species such as *Lithocarpus sp* and *Quercus sp* are found in most of this region, for that reason, the charcoal supplies from these sources are preferred by most of the end users. Therefore, the numbers of villages producing charcoal are also more in Champhai district and the pioneer villages producing charcoal on commercial scales are also located in this district. The choice of species to produce charcoal can be depended on two factors. The first factor is the availability of plant materials. Some species are very less used or not frequently used because there are few individuals of these species in the zone. The second factor to choice species for producing charcoal is based on the quality of the wood. Three important elements have repercussion on the quality of charcoal: the plant species, rate of humidity and rate of lignin. The hard wood produces more charcoal compared with light wood (Sponsel *et al.*, 1996). However, due to lack of availability of such desired species, even the less preferred species are also utilized for charcoal making. As such is the case in those districts of Mamit, Lunglei and Kolasib; which have less dense wood of less preferable tree species. Njenga *et al.*, (2013) supports that since there is particular consumer preference for specific tree species used to produce charcoal, increase demand will mean massive harvesting of the particular species. This is due to the fact that the availability of the choice species was decreasing owing to deforestation and other human activities on forest vegetation. Girard (2002) stressed that in places where high fuelwood and charcoal consumption and weak supply sources put strong pressure on existing trees resources, which is the case in rural villages of charcoal production areas in Mizoram.

A standard charcoal is packaged using gunny bags of used rice sacks weighing 18-25kg of charcoal with twine ropes woven on top of the sack to secure the charcoal. Nevertheless, the weight varies with the quality and source of charcoal. The rate of charcoal from the producer is also fluctuated on seasonal as well as sources, however, each district have their own rate as controlled by the producers, subsequently, almost all the prices within one district is more or less same. There is uniformity in the charcoal prices in the production areas mainly where there are producers' associations, because the charcoal price is decided jointly by all producers. However, a limitation is the lack of clear procedures for the price definition. For example, given that there is less amount of charcoal produced in Mamit district, the price is controlled by the lone producer itself. It is also learnt that there is a peak season for charcoal demand, since there is more demand during winter i.e. late October to early March, the production is also at peak during this time, hence the price of charcoal also tend to rise accordingly. The price also varies with district wise, which is not only due to the availability of good quality of charcoal, but mainly due to the abundance and scarcity of the charcoal as a whole.

Market trends normally follow the demand trends. The city is less affected with descend in demand due to the diverse end usages. Nonetheless, the retailers affirmed that the market is amplified during the winter season because of the rise in demand for house/ space warming by the households. On the other hand, maximum usages of charcoal are observed in tea stall and local restaurants for cooking space warming. In the mean time, there is continuous demand and flow of supply to some usages such as blacksmiths, hostels, local distilleries, etc. Owing to the diverse usages of charcoal, the numbers of retailers and traders are also maximum in the city where most of the participants are found to be female, who are dealing with other business at the same time selling charcoal for extra income. Except in Serchhip, Lawngtlai and Siaha, charcoal trade is dominated by females.

## 5.2 Wood and charcoal quality

Forests covering one third of its land mass protects the earth, nurturing the life on its surface as major terrestrial carbon pool (Melillo *et al.,* 1990; Roberntz *et al.,* 1999). Wood represents dominant pool of carbon out of innumerable forms (Lamlom and Savidge, 2003) existing in forest ecosystems. The increasing population demands increasing amounts of fuels for cooking. However, energy from biomass fire wood or charcoal reduces forest coverage leading to depletion in the woody biomass which has direct effect on the rate of carbon released into the earth atmosphere (Al Mamun, 2007). Charcoal quality and its production depend on a set of chemical, physical, mechanical, and anatomical properties of wood, usually these are interdependent (Pereira *et al.,* 2012). During the present study 10 potential charcoal generating species have been compared about properties of charcoal and top 8 species about wood qualities along with effect of charcoal production on soil, environment and health effect. The outcomes obtained have been discussed with valid reasons and implications under the present chapter as below:

### 5.2.1 Physico-chemical properties of wood

***Calorific Value (MJ/Kg)***

Species studied recorded highly significant variations with respect to calorific value (MJ/Kg) among them except few at par groups existed and the values ranged between 16.5% to 17.5%. Maximum calorific value was found in *L. polystachyus* and minimum with *S. wallichii* in our study. Agroforestry database collaboratively developed by British Department for International Development (DFID), the European Union and the World Agroforestry Centre (ICRAF) speaks calorific value of *Acacia auriculiformis* to be 4500-4900 kcal/kg, calorific value of sap wood content of *Acacia catechu* to be 5142 kcal/kg and heartwood is 5244 kcal/kg, that of *Acacia mangium* as 4800-4900 kcal/kg. The calorific value of *Bauhinia variegata* is 4800 kcal/kg. The calorific power of biomass is reflection of its chemical composition. Further, the calorific power increases with increasing the content of lignin. The cellulose has a lower calorific power than the lignin because of the high degree of oxidation. The hydrocarbon content also increased the calorific power of biomass (Voicea *et al.,* 2013). Variation of calorific values among species can be attributed to the chemical composition of the sample materials. Lignin and extractive content have a considerable influence. According to Kaltschmitt *et al.,* (2009), lignin, cellulose and hemicelluloses have a net-heat of combustion of 27.0, 17.3 and 16.2 MJ/kg, respectively. The gross-heat of combustion of cellulose, lignin and extractives isolated from *Gmelina arborea* (Roxb) have been determined by Fuwape (1989) with 19.7, 25.4, 25.1 MJ/kg, respectively. Therefore, the higher the lignin and extractive content of a material, the higher the respective calorific value (White 1987 and Demirba¸ 2001).

***Ash content (%)***

Ash content of tree wood revealed that highly significance difference among the charcoal wood species studied existed with maximum ash content (3.02%) in *Q. helferiana* and minimum ash content (0.75%) in *L. polystachyus* except some non-significant groups existing among species studied. Saikia *et al.*, (2007) analysed ash content of bamboo species of North Eastern India to be *B. tulda* (4.01 %), *B. balooca* (3.98 %), *B. bambos* (3.79 %), *B. pallid* (4.45 %), *M. bamboosoides* (3.28 %), *T. dollooa* (4.21 %), *D. hamiltonii* (4.33 %), *B. nutans* (4.20 %). Pereira *et al.*, (2012) the ash content of Eucalyptus clone found varying between 0.33 to 0.64 %. Ash biomass material is a measure of non-combustible materials present in it (Saikia *et al.,* 2007). Pettersen (1984) found ash content in forest plant varying between 0.3 to 1.4%. Werkelin *et al.,* (2011) found ash forming elements are significantly different for three parts of each tree species, where foliage contains much higher contents of ash and elements such as K, P and S. Critical ash forming elements in forest residues, ash related problems such as slagging and fouling are expected to occur during combustion process (Ohman *et al*., 2004). In Norway spruce, the ash content of the bark was 1.49-2.11 %, which is 8-10 times of those of the corresponding stem wood. The branch and top have high ash contents about 1.17-1.89% (Wang and Dibdiakova, 2014).

***Carbon content (%)***

The analysis revealed that carbon content of the wood sample of the species significantly varied with exception of some non significant groups. Maximum carbon content was recorded in the wood sample of *L. polystachyus* (45.97%) and minimum with *Q. helferiana* (43.7%). Carbon content of wood varies 47–59% (Hollinger *et al.*, 1993; Ragland *et al.*, 1991) depending on the species. Further, it has been reported that even growing the same species in different geographical locations can result in readily detectable differences in wood properties (Zobel and Sprague, 1998; Zobel and van Buijtenen, 1989). Lamlom and Savidge (2003) recorded carbon content of *Quercus alba* 49.57% and that of *Q. rubra* 49.05%. They further reported that in North American trees, wood in mature stems of hardwood species was ranging from 46.27% to 49.97% (average 48.41%), and that in softwood species from 47.21% to 55.20%. Higher carbon content in softwood has been put the reason that higher (about 10% more) lignin content in softwood (Savidge, 2000).

***Density (g/cm$^3$)***

Glass and Zelinka (2015) revealed that for materials that adsorb moisture but do not change volume, such as stone and brick, the density depends upon moisture content. For these materials, the density can be calculated at any moisture content as the ratio of mass to volume, and the relationship between density and moisture content is linear for wood, both mass and volume depend on moisture content. However, the oven dry density of most wood species falls between about 320 and 720 kg/m$^3$ (20 and 45 lb/ft$^3$), the range actually extends from about 160 kg/m$^3$ (10 lb/ft$^3$) for balsa to more than 1,040 kg/m$^3$ (65 lb/ft$^3$) for some other imported woods. In our case, the density of the wood sample studied from charcoal wood species expressed a range from minimum 0.521 g/cm$^3$ in *L. dealbatus* and to 0.703 g/cm$^3$ in *L. polystachyus*. Species were observed to be highly significantly differed with respect to wood density besides few at par groups. The average basic specific gravity of white ash is 0.55 g/cm$^3$ (Glass and Zelinka, 2015) at 12% MC density is 678 kg/m$^3$ (42.2 lb/ft$^3$).

***Moisture content (%)***

Wood is hygroscopic; it takes on moisture from the surrounding environment. Moisture exchange between wood and air depends on the relative humidity and temperature of the air and the current amount of water in the wood (Glass and Zelinka, 2015). Species studied were having much variation with respect to the moisture content. Moisture relationship has an important influence on wood properties and performance. Moisture content of wood samples ranges were from 36.7% in *L. dealbatus* to 55.75% in *L. polystachyus*. Some species had at par relations in between with respect to moisture content of wood sample. Moisture content of heart wood of willow was 82% and that of sap wood of willow was found to be 74% (Glass and Zelinka, 2015).

### 5.2.2 Physico-chemical properties of charcoal

Charcoal is the lightweight black carbon and ash residue hydrocarbon produced by removing water and other volatile constituents from animal and vegetation substances. Charcoal is usually produced by slow pyrolysis — the heating of wood or other substances in the absence of oxygen. The advantage of using charcoal instead of just burning wood is the removal of the water and other components. This allows charcoal to burn to a higher temperature, and give off very little smoke (regular wood gives off a good amount of steam, organic volatiles, and unburnt carbon particles — soot — in its smoke (Wikipedia, the free encyclopedia). Riley and Brokensha (1988) and Hines and Eckman (1993) described the desirable criteria for firewood species as rapid growth, high volume production, wood dense with a low moisture content, relatively easy to cut, easy to handle, slow burning with high calorific value, producing very little smoke without objectionable nor toxic fumes and neither spits nor sparks. Besides, other criteria includes the quality of charcoal is defined by various mostly inter-related properties that are measured and appraised separately. The physical properties of charcoal include apparent density, gross heat of combustion while chemical properties include moisture content and volatile matter, fixed carbon and ash content. FAO (1962) suggested specific gravity of 0.7-0.9 for efficiency and ease of manufacture charcoal. This is because high moisture content lowers the calorific or heating value of the charcoal (FAO, 1985).

The volatile matter in charcoal can vary from a high of 40% or more down to 5% or less (FAO, 1985). High volatile charcoal is easy to ignite but may burn with a smoky flame while low volatile charcoal is difficult to light and burns very cleanly. However, high volatile charcoal is preferable for some purposes such as barbecue, while other utilizations as chemical purification and metal manufacture need low volatile charcoal. According to Ogunsanwo (2001), one of the promising solutions to the problems of unutilized agricultural residues and wood waste is the application of charcoal production technology by knowing which wood species has the highest heating value and low ash content.

***Density (g/cm$^3$)***

Fuwape (1993) observed that in *Leucaena leucocephala* moisture content in wood was 16.64% and whereas it was 7.42% in charcoal. Specific gravity of *Leucaena leucocephala* was 0.60 g/cm$^3$ and in charcoal it was 0.29 g/cm$^3$, teak was having moisture content of wood 24.55% of charcoal 6.85% and specific gravity of wood 0.49 g/cm$^3$ and for charcoal it was 0.25 g/cm$^3$. Significant variation ($P<0.05$) was observed among the density of charcoal originated from studied species of Mizoram except some non-significant groups observed. Maximum density of charcoal *L. dealbatus* (0.363 g/cm$^3$) and minimum with *L. monopetala* (0.206 g/cm$^3$) was observed. El-Juhany *et al*., (2003) found density of *Acacia amplecips* (g/cm$^3$) 0.901, *Acacia asak* 0.687 g/cm$^3$, *Acacia salicina* 0.681 g/cm$^3$, *Acacia karroo* 0.650 g/cm$^3$, *Acacia negrii* 0.629 g/cm$^3$, *Acacia seyal* 0.627 g/cm$^3$, *Acacia stenophylla* 0.564 g/cm$^3$. Megahed *et al*., (1998) reported specific gravity of 0.621 g/cm$^3$ and 0.623 g/cm$^3$ for the wood of six years old *A. amplecips* and *A. karroo*, respectively. FAO (1962) suggested specific gravity of 0.7-0.9 g/cm$^3$ for efficiency and ease of manufacture charcoal.

***Moisture content (%)***

Charcoal straight from the kiln has very little moisture, usually less than 1% (FAO, 1987). Thereafter, it absorbs moisture of between 5 - 10% and when not properly stored, it may contain moisture of up to 15% due absorption of rain water (FAO, 1987). Moisture negatively affects the combustion properties of charcoal. It reduces its calorific value since the water in it has to be evaporated during burning. The moisture content of all charcoal almost reduced to 10$^{th}$ part of its respective wood sample. Further, there was highly remarkable variation among the three species with respect to the moisture content of their respective charcoals except few non-significant groups as studied from statistical analysis. Saikia *et al.,* (2007) found moisture content of bamboos charcoal like *B. tulda* 11.58%, *B. balcoa* 11.74%, *B. bamboosa* 12.34%, *B. pallida* 11.96%, *M. bamboosoides* 10.78%, *T. dollooa* 11.14%, *D. hamiltonii* 11.61%. El-Juhany *et al.,* (2003) found moisture content of *Acacia amplecips* 5.53%, *Acacia asak* 5.35%, *Acacia salicina* 6.24%, *Acacia karroo* 5.38%, *Acacia negrii 6.81%, Acacia seyal* 6.13% and *Acacia stenophylla* 7.19%.

***Friability (%)***

FAO (1985) spoke friability test measures the case with which the charcoal fractures into smaller pieces, when subjected to repeated handling and, thus, indicates the extent to which pieces will break up during transport, or during descent in a blast furnace. It is being a qualitative parameter for charcoal marketability as learnt from the respondents. Usually charcoal fines are either discarded or sold to blacksmiths by the charcoal traders, thus, more fines means less marketability. Further, laboratory analysis marked highly significant variations among the species with respect to their friability of charcoal of course certain non-significant groups observed. Maximum friability with *B. variegata* (15.305%) and minimum with *L. dealbatus* is observed. Therefore, the lower the per cent figure the better the charcoal.

***Carbon content (%)***

El-Juhany *et al.,* (2003) has revealed that *Acacia negrii* produced charcoal with the highest fixed carbon content (62.63%) among the investigated acacia species while *A. karroo* had the lowest value (56.92%). The fixed carbon content of charcoal ranges from a low of about 50% to a high of around 95% (FAO 1985). Thus charcoal consists mainly of carbon. The charcoal produced from both *A. amplecips* and *A. negrii* which had the highest gross heat of combustion values had also higher fixed carbon content. The same relationship was reported previously (Stimely and

Blankenhorn, 1985; Megahed *et al*., 1998). The finding of the present study concurs with the results of Megahed *et al*., (1998) for six woody species included *A. amplecips, A. stenophylla* and *A. karroo*. However, the desirable criteria for charcoal presented by FAO (1962) defined the fixed carbon content of finished product as >75 %. Proportion of fixed carbon content can be controlled through maximum temperature and its residence time during the carbonization process (Hindi, 1994). Increasing the fixed carbon content of charcoal in such a way is associated always with decrease in charcoal yield (Christiana *et al.*, 2014).

Carbon content of charcoal in our study expressed a remarkable variation among the tree species studied with highest value (85.306%) with *L. monopetala* and lowest with minimum (55.859%) with *S. wallichii* with highest carbon content of charcoal was observed to be *L. monopetala* (85.306%) and lowest with *S. wallichii* (55.859%). Fixed carbon of charcoal ranges from a low of 50% to a high 95% (FAO, 1987). Charcoal, therefore, consist mainly of carbon. The fixed carbon content is the difference, in percent, from 100 of the other constituents (moisture, ash, volatiles) (Hibajene and Kalumiana, 2003).

***Ash content (%)***

Ash content of charcoal as undesirable indicator for marketability as observed from the study site. Nevertheless, the highest ash content of charcoal was observed was with tree species *Q. helferiana* (6.077%) and least with *S. wallichii* (0.728%), simultaneously highly significant variations among the species too observed among the tree species investigated except few non-significant groupings. Saikia *et al.*, (2007) found among bamboo ash content to be *B. tulda* 3.56%, *B. balooca* 2.42%, *B. bambos* 3.45%, *B. pallida* 3.21%, *M. bamboosoides* 3.08%, *T. dollooa* 3.12%, *D. hamiltonii* 3.29% , *Acacia a mplecips* 5.37%, *Acacia asak* 5.20%, *Acacia salicina* 4.53%, *Acacia karroo* 6.42%, *Acacia negrii* 3.22%, *Acacia seyal* 7.02%, *Acacia stenophylla* 5.70%. Ash content of charcoal produced from acacia species varied significantly with higher proportions were found in the charcoal of both *A. seyal* (7.02%) and *A. karroo* (6.42%) and lower proportion for those of both *A. salicina*

(4.53%) and *A. negrii* (3.22%). The ash content of charcoal varies from about 0.5% to more than 5% depending on the species of wood.

Hibajene and Kalumiana (2003), revealed the ash content of charcoal is determined by heating a weighed sample to red heat with excess air to burn away all combustible matter. The residue, ash, which is mineral matter, occurs in the form of silica, calcium and magnesium oxides which are present in the original wood and also picked up as contamination from the earth during processing. The ash content depends on the species of wood, amount of bark included in the wood put into the kiln and the amount of earth and sand contamination. It varies from 0.5% to more than 5%. Good quality charcoal has about 3% ash content (FAO, 1987).

***Calorific Value (MJ/Kg)***

Konwer *et al.*, (2007) found calorific value of *Ipomoea carnea* charcoal 13.87 MJ/kg for wood 17.29 MJ/kg for charcoal at 300 °C and increases with temperature Calorific value of charcoal found to be higher than its respective wood that corroborated from the respondents' and laboratory inventories. Nevertheless, calorific value of charcoal was varying between 27.53 MJ/kg in tree species *S. wallichii* upto 29.943 MJ/kg in tree species *L. polystachyus*. According to Tsoumis (1991), presence of high mineral matter components in wood is not desirable, because they are not degraded during carbonization and they remain in charcoal as an undesirable residue (ash) which also contributes to the reduction of charcoal heating value. Charcoal that had lower moisture content gave often-higher gross heat of combustion or heating values. This is because high moisture content lowers the calorific or heating value of charcoal (FAO, 1985). Among the species, highly significant variation with respect to calorific value of charcoal except few at par groupings among the species. Saikia *et al.,* (2007) detected calorific value of charcoal of bamboo of NE India to be *B. tulda* 20.33%, *B. balcoa* 22.61%, *B. bamboosa* 21.96%, *B. pallida* 21.73%, *M. bamboosoides* 21.46%, *T. dollooa* 20.38 %, *D. hamiltonii* 20.96, % *B. nutans 20.81%.*

***Volatile matters (%)***

Volatile matter in charcoal of Acacia species ranged from 27.25% (*A. negrii* and *A. stenophylla*) to 31.56% (*A. asak*). The proportions of volatile matter in the charcoal of other Acacia species did not significantly differ (El-Juhany, 2003). The field survey has confirmed a permissible range of volatile matter in charcoal production from wood. Among the species very highly significant variation was observed with respect to the volatile matters in charcoal governing their charcoal qualities. At the same time highest volatile matter was with *S. wallichii* (43.413%) and least with *L. monopetala* (12.557). Hibajene and Kalumiana (2003) found volatile matter in charcoal varies from less than 5% to about 40% and is measured by heating, in absence of air, a weighed amount of dry charcoal. Volatile matter in charcoal varies from less than 5% to about 40% and is measured by heating, in absence of air, a weighed amount of dry charcoal at 900 °C to constant mass. The mass loss being the volatile matter content, while the remains is ash. High volatile charcoal is easy to ignite but may burn with a smoky flame while low volatile charcoal is difficult to light and burns very cleanly (Christiana *et al.*, 2014). Charcoal with high amounts of volatiles is easy to ignite, burns with a flame but most likely with much smoke and is more hygroscopic, less friable and thus producing less fines during transportation and handling. When volatiles are low, charcoal is difficult to ignite, but burns cleanly without a flame. According to Oliveira (1990), regarding quality of charcoal, lower levels of volatiles in charcoal is associated with high level of lignin and low level of extractives in wood. Commercial charcoal has a volatile content of about 30% or less (FAO, 1987).

### 5.2.3 Conversion efficiency

Charcoal making kilns can vary greatly in structure and size, from simple earth mound kiln to semi permanent brick ovens to large and permanent metal structures. Carbonization creates a fuel of higher quality than the original fuelwood because of inherent inefficiency in the process (Kokou *et al.*, 2009). From the study it was found that the methods employed for producing charcoal were the traditional kiln and pit method. It is revealed from the experiment of wood-to-charcoal conversion in air dried raw material, that the conversion efficiency was 22% in kiln method and 16% in pit method (**Table 4.12**). About the half of the world's charcoal use is in Africa, where traditional production techniques lead to low conversion efficiency (Kammen & Lew, 2005) Comparing the efficiency with other methods from other countries, it can be concluded that the present methods of charcoal production in Mizoram are still highly inefficient.

It was found that those areas producing charcoal in commercial scale utilize more efficient method of production *viz.* traditional kiln method, which produces more quantity of charcoal in a given material as compared to traditional pit method by providing more profit to the producers.

## 5.3 Impact of charcoal production on environment

### 5.3.1 Raw materials status

It is quite difficult to determine the deforestation rate caused by charcoal production. Besides, some of the charcoal is produced using wood in gardens being prepared for growing crops (Kalumiana *et al.*, 2003), and as such deforestation should be attributed to farming. In the study it was revealed that even though all forms of wood could be used for charcoal but certain kind of trees are preferred to others. In all the districts in which the survey was done, the major and preferred tree species for fire wood and charcoal are *L. dealbatus, L. polystachyus, L. pachyphyllus, Q. helferiana, C. tribuloides,* etc. It was established that species choice for charcoal production was highly dependent on tree availability rather than the quality of charcoal. The implication of this finding is that a preferred species will suffer massive harvesting. This is due to the fact that the availability of the choice species was decreasing owing to deforestation and other human activities on forest vegetation. Girard (2002) stressed that in places where high fuelwood and charcoal consumption and weak supply sources put strong pressure on existing trees resources; which is the case in rural villages of charcoal production areas in Mizoram.

The pit method of charcoal production inflicts damage to the vegetation. As observed from the major charcoal producing sites in the research communities, this process has several weaknesses. In a FGD, charcoal producers admitted that the charcoal producing process often caused bushfires. The researchers considered these as having implications for the sustenance of flora and fauna in the communities. It is further observed that the vegetations around the numerous mound areas were lost. An expert view elicited from the Renewable Energy Section of the Energy Commission revealed that the traditional method of charcoal production is inefficient, unhealthy and unfriendly to the environment (Ottu-Danquah, 2010). The destruction of the forest has the tendency to compound the already increasing temperatures and unfavourable rainfall regimes as argued by Friends of the Earth (2002) and Msuya *et al.*, (2011). The method of charcoal production (pit) and the process used (direct extraction of live trees from the forest without commensurate replacement) were observed as causes of deforestation. Charcoal residues and charred biomass left on the kiln sites improve soil fertility, however; charcoal production causes environmental pollution. It is therefore useful to consider oxygen limited charcoal production strategy (bio-char) in order to manage soil health and sequester carbon (Nigussie and Kissi, 2011). The forests were unable to replenish itself because of excessive extraction for charcoal production. In kiln method of production, the materials are collected from farm land (jhum), less extraction is observed, however, the choice species are also decreasing immensely since there is no intention of reforestation and replanting. It was observed that most of the villages were facing the problem of declining tree species since the rotation period of the fallow land become shorter due to limited area of arable land around their respective villages. Adverse impact that are already apparent but which would increase if the trend continues are: soil erosion, less biomass available for all other uses, traditional economic forest products such as fruits, nuts, medicinal trees becoming scarce, and more land being opened for cultivation but fall in agricultural productivity.

### 5.3.2 Health indicators

Charcoal production entails much strenuous work for the producer during felling, cross cutting, log haulage, kiln building and management. Accidents also occur which sometimes lead to serious injury. Another health risk to the producer is the exposure to gases and smoke and also heat from the kiln. Of all the gases emitted, Carbon Monoxide (CO) is the major health risk. At the same time products of the combustion process are emitted for instance Carbon Monoxide (CO), Carbon Dioxide ($CO_2$), Water ($H_2O$) and Hydrogen (H) (Commonwealth Science Council, undated). Some of the gases produced, namely carbon monoxide, as well as some oils and acids pose great risks to the producer (Hibajene and Kalumiana, 2003). However, from the study it was revealed that, 46% of the total respondents had complaints about physical injury such as back ache, sore hands, burns, cuts and other minor injuries while working in charcoal production, whereas 13% stressed about general sickness in the form of general exhaustion, chest pain, cough, slight respiratory problems, eyes tearing, etc. Charcoal consumption attributable to rural households has increased by over 300% so that in 2000, nearly half of all charcoal consumption is attributable to rural households. Ellegård (1993) in a survey among charcoal producers in the Chisamba area near Lusaka obtained an indication of the type of discomforts experienced by producers. The charcoal trade has important implications for: – Indoor air pollution and public health – Greenhouse gas emissions – Forest cover with potentially conflicting impacts on social welfare resulting from these factors: tree felling, GHG emission (CO2, CO,CH4, NO2, N2), brushwood burning, kiln covering, wood carbonization (500-700°C). So far, based on the observations, about half of the respondents engaged in charcoal business do not have any health complain. Currently, little is known on the dynamics of charcoal production in terms of ecological and socio-economic impacts. If managed effectively, charcoal is a sustainable energy source and can contribute substantially to reducing carbon emissions and greenhouse gases (Iiyama *et al.*, 2014).

### 5.3.3 Soil Characteristics

Charcoal production and related fires (land clearing fire) are expanding its scope and magnitude in many tropical catchments (Ayodele *et al.*, 2009). The sharp population increase which results in a higher demand for food, fiber and energy, along with the low level of agricultural mechanization, instability of power supply and unstable rainfall patterns, culminating in drought, are among the other factors

(Ajayi, 2004). In their study from tropical watershed in Indonesia, Ketterings *et al.*, (2000, 2002) reported that severe burning associated with these processes have a drastic effect on soil texture, color, mineralogy and other soil properties. Beringer *et al*., (2003) observed an albedo reduction of about 50 % in post-fire areas. Tryon (1948) studied the effect of charcoal addition on the available moisture in soil of different textures. A positive effect of 18 % increase in soil water retention was observed upon addition of 45 % (by volume) charcoal to a sandy soil while a decrease of about 20 % was noted for a clay soil, whereas no change was recorded for a loamy soil, under the same charcoal treatment. Therefore, improvements of soil water retention by charcoal ameliorations may only be expected in coarse-textured soils or soils with large amounts of macropores (Glaser *et al.*, 2002). Changes in soil hydraulic properties showed the potential effects of charcoal production on surface hydrology at the plot scale. Present findings of soil properties have been discussed as below:

***Carbon content (%)***

The analysis of soil samples from charcoal production area and adjacent area followed through both kiln and pit methods revealed that pit method had significantly more soil carbon (0.703 %) compared to its respective kiln counterpart (0.507 %). This could be due to the presence of carbon rich charcoal and charred biomass (Nigussie and Kissi, 2011). On the other hand, taking soil samples from charcoal production area and adjacent area it has been found highly significantly more carbon content in adjacent area irrespective of method of charcoal production. Interaction of production method and soil sampling site has no effect (non significant) on soil carbon content. Chidumayo and Chidumayo (1984), found charcoal kiln area has 1.86% and adjacent area 4.05% in Chitemalesa, east of Lusaka.

***Nitrogen (%)***

In Chitemalesa, east of Lusaka Charcoal kiln area is 0.16% and its adjacent area 0.11% of total nitrogen (Chidumayo and Kalumiana, 1991). The soil nitrogen content as indicator for plant growth and rhizosphere interaction was varying significantly with distance of sampling from charcoal production area. While comparing both the methods, pit method became nitrogen enriching than kiln method, both were having their respective soil nitrogen values to be 0.389% and 0.351%. It is ironical to record significant variation of nitrogen content of soil between charcoal production area and the adjacent area, however, their order was not uniform depending on method of charcoal production; pit method reduced soil nitrogen at charcoal production area than adjacent area but the reverse trend in case of kiln method. Charcoal production method has not only affect soil nitrogen content but also the quantum of effect was dependent on place of sample collection.

***Available Phosphorus (mg/kg)***

Significant relation was observed between charcoal production area and adjoining area with respect to phosphorus content of soil. Interestingly, both the charcoal production methods had recorded higher soil phosphorus content in their respective charcoal production areas than their adjoining areas. Method of charcoal production had highly significant effect on soil phosphorus content. Pit method had higher soil phosphorus (1.934 mg/kg) than kiln method (1.585 mg/kg). Available phosphorus was at the charcoal site is significantly higher at kiln site (Nigussie and Kissi, 2011). Interaction between method of charcoal production and site of soil collection was having non-significant effect. In Chitemalesa, east of Lusaka, also shows charcoal kiln area higher than adjacent area (Chidumayo & Kalumiana, 1992)

***Calcium (cmol/kg)***

Kiln method has higher calcium accumulation (0.167 cmol/kg) than pit method (0.082 cmol/kg). Calcium content of soil was observed to be non- significant when compared soils under both the methods of charcoal production, compared soil samples from charcoal production area and their interaction. Chitemalesa, east of Lusaka, charcoal kiln area revealed comparatively higher than adjacent area (Chidumayo and Kalumiana, 1992).

***Mg (cmol/kg)***

In Chitemalesa, east of Lusaka, Charcoal kiln area has 1.88 cmol/kg and adjacent 1.61 cmol/kg (Chidumayo and Kalumiana, 1992). More soil Mg content (0.212 cmol/kg) was observed with Kiln method than pit method (0.199 cmol/kg) both were varying significantly. Further, magnesium content of soil was varying non-significantly between two sampling sites (higher with charcoal production area than adjoining area) and non-significantly between their interactions (sites and methods). Oguntunde *et al.,* (2008) and Glaser *et al.,* (2002) also reported higher Mg content at kiln site.

***Na (cmol/kg)***

An experiment in Chitemalesa, east of Lusaka, revealed charcoal kiln area has a higher content of Na as compared to the adjacent area (Chidumayo and Kalumiana, 1992). Charcoal production area compared with adjoining area had more Na content of soil under both the methods of charcoal production. The concentration of Na in soil was observed to be non-significantly varying with site of soil sample collection (charcoal production area or adjoining area), method of charcoal production i.e. between pit (0.059) and kiln method (0.047) and the interaction between site of sampling and method of charcoal production. It was also concluded by Oguntunde *et al.,* (2008) and Glaser *et al.,* (2002) that higher Na content at kiln site than the adjacent soil.

***K (cmol/kg)***

There was marginal and non-significant difference in concentration of soil K between kiln method (0.225) and pit method (0.206) of charcoal production areas. Further, potassium content of soil has no remarkable difference between charcoal production area and adjoin area irrespective of method of charcoal production of course charcoal production area had slightly more K concentration in soil. The interaction between site of collection of soil and method of charcoal production had no significant effect over concentration of soil K. Chidumayo and Kalumiana (1992), Oguntunde *et al.,* (2008) and Glaser *et al.,* (2002) also reported more K concentration in charcoal kiln area against adjacent area.

***Exchangeable Acidity (cmol/kg)***

Charcoal production process on an average increased exchangeable soil acidity. Significant difference between 2 sampling sites namely, charcoal production area and adjoining areas were observed in exchangeable soil acidity content with more values charcoal production areas than respective adjoining areas irrespective of method of charcoal production. Pit method (0.556) had significantly higher exchangeable acidity in soil than kiln method (0.472). The interaction between method of charcoal production and site of sample collection has non-significant effect over soil exchangeable acidity. Chidumayo and Kalumiana (1992), revealed higher EA at charcoal kiln site.

***Cation Exchange Capacity (cmol/kg)***

Method of charcoal production had significant effect (kiln method had more i.e. 1.123 than pit method i.e. 1.102) but the interaction between method of charcoal production and site of soil sample collection had non-significant effect on cation exchange capacity of soil. Therefore, soil samples from charcoal production areas gave more CEC than the adjoining areas. The higher values of CEC at production site may derive from vast surface area and complex pore structure of charcoal residues and high amount of soil organic matter at charcoal production site (Nigussie and Kissi, 2011; Glaser *et al.,* 2002; Ogundele *et al.*, 2011; Oguntunde *et al.,* 2004).

***pH***

Charcoal production areas had highly significantly more soil pH than adjoining areas under both the methods of charcoal production and charcoal production had reduced soil acidity. Oguntunde *et al.*, (2004) in Ghana observed a significant increase in soil pH. Highly significant variations in pH of soil when compared soils under pit method and kiln method (Kiln method site had soil pH 5.334 and pit site had soil pH4.798) of charcoal production and significant variation among the interactions of 2 sites and 2 methods. The increase in soil pH at kiln site could be due the presence of ash which is rich in basic cations (Lehmann *et al.,* 2003 and Ogundele *et al.,* 2011). Another reason for high soil pH at kiln site could be because of porous nature of the charcoal that increases CEC of the soil. Thus there could be a chance for Al and Fe to bind with the exchange site (Nigussie and Kissi, 2011). Also observed in Chitemalesa, east of Lusaka, Charcoal kiln area 7.0 and adjacent area was 6.1 (Chidumayo and Kalumiana, 1992). The soil pH increased at the kiln level by the provision of rich ash bases during the carbonization.

***Bulk Density (g/cm$^3$)***

Pit method had significantly soil less bulk density (1.2855) than kiln method (1.324). Bulk density of soil was marginally but non-significantly decreased in charcoal production areas when compared with adjoining areas. The smaller bulk density at kiln site could be because of complex pore structure of charcoal residues left on the kiln site. As reported by Nigussie and Kissi (2011), higher sand fraction at charcoal production site may also be responsible for the reduction of soil bulk density at earth kilns. Oguntunde *et al.,* (2008) and Ayodele *et al.,* (2009) also reported reduction in bulk density at charcoal site when compared to adjacent field soils. The interaction between site of soil sample collection and method of charcoal production followed had no effect over soil bulk density. Soil bulk density in the control plots ranged from 1.1 to 1.5 g/cm$^3$ while at the plot subjected to heat, it ranged from 1.2 to 1.6 g/cm$^3$. Ueckert *et al.,* (1978) observed no change in bulk density due to soil heating. Generally, the soils were loamy sand textured. Total porosity was 45.7 %. Additions of charcoal amendment have been reported to increase macroporosity and total porosity (Piccolo *et al.,* 1996) whereas no significant effect from soil burning was observed (Ueckert *et al.,* 1978).

***Electrical Conductivity (dS/m)***

Electrical conductivity of soil was non-significantly higher in charcoal production areas than adjoining areas. Pit method (0.3675) had produced significantly higher electrical conductivity than kiln method (0.3315). The higher values of EC at the kiln site could be because of the presence of ashes, which are rich in basic cations, during production of charcoal (Nigussie and Kissi, 2011). In line with this, Oguntunde *et al.,* (2008), reported a significance increase in electrical conductivity at kiln site. The interaction between site of soil collection and method of charcoal production had non-significant effect on electrical conductivity of soil.

***Water Holding Capacity (%)***

The values of cumulative infiltration for charcoal production were higher than adjacent site at all times. This could be attributed to changes in the soil structure: decreased bulk density, increased porosity and sand fraction of heated soils, as reported above. The runoff was reduced by about 37 and 18 % (Ayodele *et al.,* 2009). Ulery and Graham (1993) stated that the coarsening of severely heated surface soils may eventually lead to a poor water-holding capacity, however, the study reveals that charcoal production areas had highly significantly higher water holding capacity of the soil compared to soils of adjoining areas. The relative change in water holding capacity regardless of small clay content at charcoal production site could be because of the presence of charcoal residues and charred biomass left on the kiln sites. Small pores in the charcoal residues and charred biomass increases soil water holding capacity of the soil. The presence of charcoal may affect soil physical properties such as soil water retention and aggregate stability, leading to enhanced crop water soil. Glaser *et al.,* (2002), also reported improvements of soil water retention by charcoal ameliorations. Method of charcoal production however had significant effect on water holding capacity of soil, with more value with pit method (65.903%) than kiln method (58.29%). Interaction between site of soil sample collection and method of charcoal production has no effect on water holding capacity of the soil.

***Particle size distribution***

The sand fraction in adjacent and production site ranged from 71 to 83% and 80 to 89%, respectively (Black and Hartge, 1986). In the study of Ayodele *et al.,* (2009), both sand and clay components of the texture were significantly varied. As compared to adjacent farmlands, clay and silt content was reduced at kiln site by 34.6 and 3.3%, respectively but the sand fraction was increased by 62.6%. The higher percentage of sand at kiln site is due to the exposure of the soils to high temperatures.

This results the fusion of clay and silt particles into sand-sized particles (Sertsu and Sanchez, 1978). Oguntunde *et al.,* (2004), also observed a significant decrease in clay fraction and corresponding increase in sand content in severely burnt soils. In our study charcoal production process had highly significantly changed soil clay (finer) composition, the quantum of which was further varying with the method of charcoal production. Pit method had more clay/ finer matter (14.75 %) than kiln method (11.423 %) method. The interaction of sampling site for soil collection and method of charcoal production had highly significant on soil finer matter (clay) composition remained. There was non-significant effect of sampling site i.e. between charcoal production areas and adjoining areas, highly significant effect of method of charcoal production i.e. between pit and kiln methods (pit method had higher i.e. 11.25% and kiln method had lower i.e. 10.667%) and non-significant effect of site and production method interaction on silt content of soil. Charcoal production areas have marginal increase in silt matter content in soil. Highly significant variation was observed between 2 sites (charcoal production area and adjoining area), between 2 methods (kiln and pit methods of charcoal production) and among their interactions in sand composition of soil. Sand composition from soil collected from kiln method had higher sand (77.91%) composition than that of pit method (74.0%).

### 5.3.4 Effect of charcoal production on agricultural crops

In addition to fire effects on soils, charcoal residues and charred biomass left on the kiln sites could serve to ameliorate and improve the fertility of tropical soils by direct nutrient addition and retention (Glaser *et al.,* 2002). It has been reported that charcoal additions to soil have positive effects on soil properties and enhance soil fertility and productivity (Ketterings and Bigham, 2000; Glaser *et al.,* 2002). Increased pH, addition of free bases such as Ca, K, and Mg and enhancement of the cation exchange capacity (CEC) have shown that added charcoal is not only a soil conditioner but also acts as a fertilizer (Glaser *et al.,* 2002). Furthermore, the addition of charcoal to soil can positively affect seed germination, crop growth and yields (Ketterings and Bigham 2000). A recent review by Glaser *et al.,* (2002) has demonstrated that crop yield can be increased upon charcoal additions to soil especially in the tropics. The experiment conducted showed that the growth and yield of both bush beans and tomatoes were significanty higher in soils collected from charcoal production sites compared to jhumland and forest soils. During the experiment, the mean temperature and relative humidity were 23.84 ± 0.91°C and 54.78 ± 5.27 % respectively. In case of bush beans, the result showed significant difference among the treatments the maximum growth and yield, were form charcoal production site, except in plant height, number of leaves and the fresh pod weight wherein an opposite trend was observed. Chidumayo (1994) reported generally better seed germination (30% enhancement), shoot heights (24%) and biomass production (13%) among seven indigenous woody plants on soils under charcoal kilns compared to the undisturbed Zambian Alfisols and Ultisols. In case of tomato, all the growth and yield parameters were significantly higher ($P<0.05$) in charcoal production compared to other two treatments. Kishimoto and Sugiura (1985) found that the heights of sugi trees (*Cryptomeria japonica*) increased by a factor of 1.26–1.35, and the biomass production increased by a factor of 2.31–2.36, five years after application of 0.5 Mg charcoal/ha. From these results it might be concluded that charcoal is not only a soil conditioner which increases the CEC (Glaser 1999; Glaser *et al.*, 2000, 2001a) but may act as a fertilizer itself. Applications of charcoal which inevitably contain ash add free bases such as K, Ca, and Mg to the soil solution, increasing the pH value of the soil and providing readily available nutrients for plant growth. The overall observation revealed that the crops grown in soil collectd from charcoal production sites showed significantly better performance in growth and yield as compared to soils collected form adjacent jhumland and forest areas.

**Chapter 6**

# SUMMARY AND CONCLUSIONS

The study was carried out in the entire state of Mizoram, covering all the 8 (eight) districts headquarters *viz*., Aizawl, Kolasib, Serchhip, Champhai, Mamit, Lawngtlai and Siaha, and randomly selected villages representing each district to investigate the production and use pattern of charcoal. However, the quality attributes, charcoal produced and evaluation of environmental impact of charcoal production sampling was carried out in Tualpui and Tualte villages of Champhai district, Mizoram. By collecting soil from the charcoal production and adjoining areas in Tualpui village of Champhai district, Mizoram, a poly pot experiment was conducted for assessment of the growth and yield of selected agriculture crops in order to apprehend the indirect effect of charcoal production on soil. The major findings of the study are highlighted herewith in the following sections:

1. The study revealed that most trees used for charcoal production are sourced from producers' own jhumland and private farms; produced by using either traditional kiln or pit method of which the conversion efficiency are considerably low as compared to other methods from other advanced methods. In most of the districts, charcoal is mainly produced from individual jhumlands in conjunction to agricultural farming so that it serves as the additional income earning opportunity, whereas it was observed that charcoal is produced by a single person from private land in Mamit district.
2. Major production of wood charcoal comes from Champhai district followed by Serchhip district, in which the earliest commercial charcoal production was found to be started in 1992 from two villages identified *viz.* Kelkang and Dilkawn of Champhai district. The overall extensive production begins from around 2010. In general, more women were involved in charcoal trading than men in charcoal trading in most of the areas.

3. Even though almost all forms of wood could be used for charcoal certain kind of trees are preferred from others. A total of 24 species are recorded for charcoal production and 10 species are preferred by the respondents, at the same time other species are also utilized whenever there is no such preferred species are available. The most desired species are dense hardwood such as *Lithocarpus dealbatus,* followed by other *Lithocarpus spp* and *Quercus spp*.
4. The vast majority (99 percent) of charcoal producers in the study area employed the traditional earth kiln for commercial charcoal production, which was introduced by Japanese for wood vinegar production, but it was later modified for charcoal production.
5. The peak season for charcoal business is during late October to early March, where the charcoal are shipped mostly by pick up and the demand is highest in Aizawl district where the tea stall/canteen contribute the highest usage. Most of the producing villages are located in remote areas with low grade link road, which become slippery and inaccessible for most of the vehicles, as such, the vehicles which can access during these adverse climatic conditions is pick up (Mahindra). Even those who own vehicle within the production villages usually have pick up as it can be employed for carrying goods and charcoal from their villages to the destinations throughout the year.
6. The charcoal quality experiment revealed that *L. dealbatus* has the highest density and low friability which is considered desirable qualities in charcoal.
7. The charcoal of *L. polystachyus* shows highest calorific value as compared to other species, which is an important attribute for the forging work; remarkably this particular species is preferred by blacksmiths.
8. Pearson's correlation shows that charcoal moisture content is positively correlated with calorific value and ash content, but negatively correlated with friability. Similarly, bulk density is positively correlated with ash content whereas fixed carbon content is negatively correlated with volatile matters content.

9. In case of wood properties, the ash content and carbon content of wood is significantly negatively correlated. Those woods, which have more ash content possess less carbon content and *vice versa*.
10. Correlation analysis between wood and charcoal properties revealed that charcoal calorific value and wood calorific value are negatively correlated. Similarly, charcoal carbon content is positively correlated with moisture content and negatively correlated with wood calorific value.
11. All physico-chemical analysis of *L. dealbatus* wood shows the species possesses most of the desirable qualities and locally most preferred too for charcoal making.
12. The study observed that the wood land resources are experiencing an extensive degradation through the unsustainable methods of charcoal production. Apparently, there are changes in the vegetative biodiversity: gradually disappearing flora, yearly observed rainfall variability and complained reduction in farm yields among others. The study again identified that the traditional method of charcoal production adopted by charcoal producers as well as their preference for particular tree species are some of the key known factors destroying the vegetation. All interviewed charcoal producers, retailers and community leaders were strongly aware of the deteriorating rangelands and the negative effects of deforestation. About 100 percent of respondents expressed their knowledge about the declining tree populations in the vicinities of their town or villages. A smaller percentage of respondents were aware of the declining population of specific trees targeted for charcoal.
13. Most respondents believed that the forests of the region will disappear, if the current unsustainable methods of land use continue, whereas fewer numbers thought that the forests will moderately or slightly decline.
14. Most of the respondents felt that the raw materials are reducing, however, those villages situated near Forest protected areas seems to feel no change.

15. The overall public health of those engaged in charcoal have some complaint on physical injuries but health condition is less affected, in the meantime some of the respondents have no complaint at all.
16. The effect of charcoal production on physical properties such as soil bulk density shows decrease in both kiln and pit method as compared to adjacent areas, meanwhile significant decrease is observed in pit method as compared with kiln method of production. Significant increase in water holding capacity is observed in the soils of charcoal production area in comparison to adjacent areas, within the method of production, pit method has higher water holding capacity. Clay is significantly increasing in charcoal production sites and pit method has higher fine particles than kiln method. Silt content is increase in both the charcoal production areas and the significant increase is observed in pit with kiln method. There is a highly significant decrease in sand percentage in charcoal production areas as compared to the adjoining areas. The soil from kiln method of production exhibit higher sand content as compared to the pit method.
17. The study reveals that the effect of charcoal production and its method also varies on the soil chemical properties; carbon content in both the methods decreases significantly in charcoal production sites, whereas in pit method has significant higher content of carbon as compared to kiln method. Nitrogen is found to be significantly increased in charcoal production area than adjoining site in kiln method, while the reverse is in pit method, which shows that more nitrogen deposition is observed in kiln method but not significant. Available phosphorous is significantly increased in both the production sites of the two methods; the pit method significantly produced more nitrogen than kiln method. As for magnesium, there is increase in production site in both the methods; however, kiln method is significantly higher in comparison to pit method. Increase in sodium is also observed in both the production sites and more amount is also noted in pit method. Charcoal production sites contain more amount of potassium and calcium as compared to their respective adjoining areas, in the meantime kiln method of

production is observed to be produced more than pit method. Due to the increase in particular bases, cation exchange capacity is also subsequently increases in production sites, comparing the methods, kiln method has significantly higher capacity than pit method of production. However, electrical conductivity is lower at production areas in both the method, significantly higher in pit method. Charcoal production area in both the method show significant increase in exchangeable acidity, also significantly higher amount is observed in pit method. The pH in both the charcoal production sites increases significantly and even highly significant increase is observed in kiln method in comparison to pit method.

18. Experiment on cultivation of agricultural crops in controlled environment shows that the growth and yield of both bush beans and tomatoes shows significant augmentation in all the parameters tested, except the height and number of leaves in case of beans.

Many people in the north-eastern region of India including the state of Mizoram are engaged in charcoal production on commercial scale which is probably due to the vegetation and availability of raw materials of the preferred dense hardwood. The charcoal producers rely on natural regeneration of the preferred tree species, which is supplemented with long rotation period of trees, consequently the availability of these particular species are observed to be declining.

The prevailing system of jhum cultivation is coexist with charcoal production, proper land use management techniques, increase wood supply through agroforestry/afforestation, along with employment of better efficiency kilns can significantly lower the impacts associated with charcoal industry and may take away the pressure from natural forests and could even become a steady source of earnings for producers.

Charcoal production is still practice at the rural areas; as a result there is no regulatory outline in place to standardize charcoal production, distribution and sales in the state, which is affecting the environmental aspect of our economy. Therefore there is a need to establish a legal regulatory framework bringing out the coordination mechanism among various stakeholders in the charcoal industry. There is also need to upkeep charcoal businesses as part of the small-and-medium scale enterprise development in the country since such business have been found to be an important source of income to many households. The use of traditional tools, combined with heavy lifting, exposure to high temperature, inhalation of particulate matter during combustion leads to common injuries and sickness as mentioned by several respondents. Therefore, design of awareness on health impacts of inhaling charcoal dust and other particulate matter is compulsory desirable. The establishment of public awareness on energy efficiency and conservation practices and health impacts in the usage of charcoal is also essential.

Adopting modern methods and technology may improve production and utilization and also may reduce the health risks associated with charcoal production. Besides charcoal quality produced from less preferable species may also be improved. Therefore, providing logistical sustenance for the concern department to develop technical support and the establishment of awareness on the implementation of improved carbonization technologies to charcoal producers is advisable.

The effect of charcoal production on soil seems to be significantly benefitting agricultural crop production which is due to improvement in soil physical and chemical properties by the enrichment of soil nutrients with biochar and its constituents.

Charcoal industry is economically valued, but it has argumentative effect on environment in terms of surrounding forest resources of the rural people who offer the benefit of cheap and dependable fuel to their urban counterparts. Most of the people interviewed were not aware of the relations between the charcoal production and the overall environment. Besides reducing the carbon stored in the forests and releasing emissions during the burning process, charcoal production and consumption also causes reduction of the forest cover, biodiversity and environmental amenities hostile the resources' sustainability as well as causing health issues. Considering at current consumption patterns, it is important that the different participants take actions to solve the problem and avoid future environmental problems. Possibilities to hold this problem include: i) propagation of improved production technologies such as the drum kilns, ii) introduction of stoves with improved efficiency, iii) providing of inexpensive alternative energy sources and iv) the introduction of fast growing species and agricultural wastes for charcoal production. Awareness raising campaigns for all stakeholders involved in the trade are desirable. Likewise, the forest should be restocked through agro-forestry judiciously guided by exploration to pinpoint suitable trees with shorter gestation periods.

The yield of charcoal also indicates some variation with the kind of wood. The mature wood of rigorous condition is preferred for charcoal production. Dense wood also have a tendency to to give a dense, strong charcoal, which is also desired. Though, very dense woods at times produce a friable charcoal because the wood tends to fragment during carbonization. The friability of charcoal increases as temperature increases and the fixed carbon content increases as the volatile matter content descents. It is endorsed that a temperature of 450 to 500°C gives an optimum balance between friability and the desire for high fixed carbon content.

There is thus a need to encourage broadening and the use of plantation species or species producing a lesser amount of dense charcoal. While less dense charcoal may have different physical properties, there is no difference in energy terms. Even though dense charcoal does undeniably hold more energy by volume, this is not the case by weight. Where the use of alternative species for charcoal making is promoted, it is necessary to re-evaluate the processes involved in the charcoal production and utilization chain. One necessary alteration is the design of energy-efficient charcoal stoves, as most of the stoves currently used are not really suitable for charcoal from lightweight species, burning it too quickly and vigorously for consumers' needs.

As the charcoal goods are moved from the point of production through markets to consumers, it sustains various costs: production, transportation, taxation and other informal costs. Thus, it is challenging to accurately present the cost benefit distribution of the business along its chain. What is understandable at this point is that the current charcoal production system does not take the tree resource into account. This is generally because charcoal makers produce charcoal from state or community forest resources free of charge.

Since charcoal business have been found to be an important source of income to many households, thus, an organized market through govt. supported agencies (such as cooperative societies) with proper trade regulation may benefit the poor charcoal producers in these remote areas to provide technical assistance and funding for programmes to transfer improved carbonization technologies and higher levels of efficiency in the production, distribution and use of charcoal. Support through technical assistance prevailing institutions for testing and guarantee of improved production and end use knowhow for charcoal. Charcoal production is every so often a seasonal activity due to less demand and road conditions of the rural areas, thus this slow down the production and also there is declining in the selling prices. Therefore, improvement of advanced production technology alongwith intervention authority to improve transportation and stockage is advisable to maintain the trade stability.

On the basis of these insights, there is the need to ensure better management of charcoal consortium particularly, from the production to end uses through effective policies in order to achieve sustainable use of the resource. Efforts may be addressed on the following:

1. Sustainability of sources of supply of raw material
2. Production of efficient technologies for charcoal production and use
3. Efficiency in the transportation of charcoal
4. Improved packaging and marketing
5. Strong organization in formal and regulatory arrangements
6. Substitution with more modern and regular supply of fuels.

**APPENDICES**

# QUESTIONNAIRES

## Producers

Enumerator:

Village: R.D. Block: District:

Age:

Main occupation?

a) Jhumming
b) Charcoal Making
c) Daily labour
d) Other (specify)____________________________

Family details:

| Name | Age | M/F | Education | Occupation | Relation |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

How many family members are involved in charcoal making?

Male _____ Female _____ Children ______

1. How long were you producing charcoal?

2. In which sites do you produce charcoal?

3. What method do you use for producing charcoal?

a) Mound method
b) Pit method
c) Other (specify) ____________

4. Do you make your own kiln? YES/NO

5. How much time is use for making a kiln?

6. How many times a single kiln can be used for production?

7. How many charcoal (bags) do you produce in a month?

8. How do you transport your charcoal to the village/home?

a) Head load

b) On animal back

c) By small trucks

d) Others (specify) _____________________

9. Which type/species of trees you prefer most for charcoal production?

| Species | Rank | Quality attributes/drawbacks |
| --- | --- | --- |

10. Where do you get the raw material from?

a) Free basis (jhum/fallow land)

b) Forest

c) Use trees on my own land

d) Pay the land owner

e) Combination of the above

11. Do you find it more difficult to access trees for charcoal production than in the past? YES/NO

12. What have been the main factors for this change?

13. Do you sell it to any agent/ direct to retailer? Who and where? Selling Price per bag?

14. Are you aware of any environmental problems caused by the use of charcoal?

15. Do you observe any effect on soil fertility due to charcoal production?

16. Any effect on biological surroundings such as crops, vegetation, birds, animals, etc?

17. Do you experience any of the following health problems from working with charcoal?

a) difficulty to breathe

b) eye irritation

c) chronic respiratory problems

d) others (specify) _______________

18. Does charcoal production cause conflict in the community?

a) never

b) only occasionally

c) sometimes

d) often

19. Is there any rule and regulation for extracting charcoal?

20. Is there any institution/body governing the management of forest?

21. Is there any regulation of controlling selling price?

## **Middlemen**

Enumerator:

Gender: Age:

Educational Level: No School ( ) Primary ( ) Secondary ( ) Above ( )

Address/Village/Town:

1. Means of transport?

2. From where do you purchase charcoal? Any prefer producer? Why?

3. In what quantities do you purchase?

4. How long have you been getting charcoal from current source?

5. For how much per unit?

6. Changes in prices for last years?

    Cost ________________

    Selling _______________

7. Do you prefer charcoal from a particular tree species?

| Species | Rank | Quality attributes/drawbacks |
|---|---|---|

8. Do you have a ready market for your charcoal?

9. Who is your main client?

    a) Household

    b) Retailer

    c) Others (specify) ______________

10. At what price and in what quantities do you sell to them?

a) Household

b) Retailer

c) Others (specify) ______________

11. How often do you sell to your clients (weekly/monthly/quarterly)?

a) Household

b) Retailer

c) Others (specify) ______________

12. Do you pay for any fees, road levies or licenses (legal or illegal) for transporting your charcoal? YES/NO

If yes, how much and to whom?

Forest officers____

Village/municipal councils ______

Others (specify) ________

13. What are the difficulties (challenges) while undertaking the charcoal transportation work?

14. Are you aware of any environmental problems caused by the use of charcoal?

**Retailer/Stockist**

Enumerator:

Gender: Age:

Location:

District:

Educational Level: No School ( ) Primary ( ) Secondary ( ) Above ( )

1. How long were you selling charcoal?

2. Why did you join the charcoal business?

3. Do you have other means of living besides charcoal business?
    a) Some livestock
    b) crop farm
    c) Any other (specify) _______________

4. From which places your charcoal comes?

5. What are the preference sources, ranking order?

6. Cost price of charcoal?

7. Selling price of charcoal?

8. Where do you sell the charcoal?

9. How much charcoal do you sell? Per day/week/month

10. Do you prefer charcoal from a particular tree species?

| Species | Rank | Quality attributes/drawbacks |
|---|---|---|

11. Does the price of charcoal vary from the suppliers?

12. How has the price of charcoal been over the last five year?

13. Do you find it more difficult to get charcoal than in the past?

14. What problems do you encounter in getting your charcoal?

15. Are you aware of any environmental problems caused by the use of charcoal?

16. What is the breakdown of the costs you incur?

| Item | Cost |
|---|---|
| | |
| | |
| | |

17. Estimate the percentage of fines in a sample bags by either feeling or asking

| Bag number | Percentage of fines | Remarks (asking or feeling) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

18. Do you unbundle the bags of charcoal you buy from whole sellers/transporters? YES/NO

19. What are the two major opportunities for charcoal selling?

20. Any threats to charcoal selling business?

## **Consumers**

Enumerator:

Gender: Age: Occupation:

Location: District:

Educational Level: No School ( ) Primary ( ) Secondary ( ) Above ( )

Family details:

| Name | Age | M/F | Education | Occupation | Relation |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

1. What type of energy does this household use for lightening?

   a) electricity b) firewood

   c) Kerosene d) Other (specify) ________________

2. What type of fuel does this household use for cooking?

   a) wood b) Charcoal

   c) kerosene d) electricity

   e) LPG f) other (specify) ___________

3. What is the main purpose of Charcoal?

   a) Cooking b) Boiling water

   c) Cooking animal feed d) other (specify) ___________.

4. How efficient is charcoal compare to other fuel?

5. How much charcoal is consumed (month/year/season)?

6. Where do you buy charcoal from?

   a) Retailer b) local vendor

   c) directly from producer d) middlemen

   e) other (specify) ___________

7. What is the cost price of charcoal?

8. Does this household used more charcoal than is used five years ago?

9. Do you prefer charcoal from a particular tree species?

| Species | Rank | Quality attributes/drawbacks |
|---|---|---|

10. Do you get sufficient charcoal from market when you need? If not, when (season)?

11. Does this household ever fail to cook meals because of lack of charcoal?

12. Do you experience any of the following health problems from working with charcoal?

a) difficulty to breathe

b) eye irritation

c) chronic respiratory problems

d) others (specify) _______________

13. Are you aware of any environmental problems caused by the use of charcoal?

## PHOTOPLATES

**Picture 1:** Logs for raw materials

**Picture 2:** Charcoal stacked for collection

**Picture 3:** Methods of charcoal production; **3.1:** Traditional pit method of charcoal production

**Picture 3.2:** Traditional kiln method of charcoal production


**Picture 4:** Transportation of Charcoal to urban and sub-urbans

**Picture 5:** Charcoal retailing shops and wholesalers in city and towns

**Picture 6:** Different end usages of charcoal


**Picture 7:** Experiment on Charcoal production soil on agricultural crops (Dept. of HAMP, MZU)


**Picture 8:** Laboratory analysis of charcoal quality

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ABSTRACT

# STUDIES ON WOOD CHARCOAL PRODUCTION, UTILIZATION AND ITS ENVIRONMENTAL IMPACT IN MIZORAM

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This thesis looks at the socio-economic analysis of charcoal production and utilization, charcoal quality attributes and its environmental impact in Mizoram. The main objective of the study was to determine the contribution of the charcoal industry to sustainable livelihood in the study area. Charcoal is produced by a process called carbonization, a process by which solid residues with increasing content of element carbon are formed from organic material usually by pyrolysis in an inert atmosphere. During pyrolysis, biomass undergoes a sequence of changes and normally yields a black carbonaceous solid, called charcoal, along with a mixture of gases and vapors. Generally, charcoal production through pyrolysis is maximized in a process of low temperatures and slow heating rates, the so-called carbonization (Anon, 2010). The factors affecting wood carbonization are - the nature of wood, wood chemical composition, wood structure and physical properties such as density, permeability, thermal conductivity, size and shape and various external conditions such as temperature, heating rate and pressure (Kataki, 2005). Charcoal can be made from virtually any organic material, like wood, straw, coconut shells, rice husks, bones. Among wood, usually the hardwood species are preferred for charcoal making e.g. Mangroves, Oaks, *Acacia, Prosopis* (Bhattarai, 1998). It can be used in smaller quantities with cheap burning devices for domestic application. According to Ellegard and Nordstrom (2003), due to its low cost compared to other fuels like kerosene and liquefied petroleum gas (LPG) as well as other factors the demand for charcoal is expected to continue rising dramatically in the coming decades, despite best efforts by modern energy advocates. Moreover charcoal has been an important domestic product for many years and, regardless of how it is produced, it has wide market acceptance for its great uses. This market has stimulated interest in the manufacture of charcoal globally. The increasing demand of charcoal as recreational fuel, and production will continue to expand as this use increases (Bhattarai,1998). The reduction in forest cover has left the charcoal producers of the state available nearby and this has in turn affected both quality and quantity of charcoal. In addition, economically important tree species are also used up in charcoal production. Therefore, extensive farming of selected tree species in available wastelands could be a viable alternative to bridge the gap between demand and supply with little choice about the selection of tree species for charcoal making. Survey has revealed that rural populations of Mizoram have strong preferences for certain tree species for charcoal production. But as resources become scarce and preferred species are not sufficiently available, presently the charcoal producers are using all kinds of tree species for charcoal production. In this regard, no systematic work has been done so far to characterize these tree species from the charcoal production point of view. Ravindranath *et al.,* (1991) opined that before undertaking any programme of biomass production, local tree species diversity, traditional preference of tree species for various purposes and information regarding the performance of different species in that area should be taken into consideration.

Additionally, charcoal trade offers income generation opportunities for many people in both urban and rural areas through small scale retail businesses mostly run by women who sell it in the urban areas as in the case in Mizoram. The practice is prevalent in areas where the local demand for charcoal is limited and the market is small, consequently the main markets are usually in the urban and sub-urban areas irrespective to the level of income. This often means that the charcoal is produced far from the demand and must be transported to the user, mostly the city and town areas, since the urban environments which is ever growing population depends on charcoal as secondary source of energy for cooking and heating, especially on commercial sectors. Ribot (1993, 1998) conducted a commodity chain analysis on charcoal industry, finding that despite substantial regulations, a majority of benefits, both economic and socio-political, accrue to merchants and wholesalers involved in the trade compared to producers. Rural producers, who often make up the largest portion of the employed force, generally lack the capital to increase their own earnings, or even maintain just above subsistence income (Post and Snel, 2003). Intertwined in charcoal production and use are global environmental effects. Because much of the charcoal feedstock is not plantation wood, the unsustainable harvesting of biomass results in net carbon dioxide emissions. In addition to the production of charcoal, pyrolysis of biomass also produces incomplete combustibles, such as methane, which may have a higher global warming impact than carbon dioxide. In fact, the main global warming impact of the charcoal cycle may result from the biomass pyrolysis and not the end-use of charcoal burning. Nevertheless, charcoal production may also have negative impact on environment and soil fertility of the charcoal production sites and its surrounding area.

It was revealed by Fontodji *et al.,* (2009) that the soil physical, chemical and microbial properties were altered. The organic matter was destroyed; it is higher at the unburnt plot level than inside the kiln. The soil pH increased at the kiln level by the provision of rich ash bases during the carbonization. Fire increased the permeability at the kiln level by raising the bulk density and the total porosity of soil. Glaser *et al.,* (2002) concluded that charcoal residues and charred biomass left on the kiln sites has been also found to serve to ameliorate and, improve the fertility of tropical soils by direct nutrient the addition and retention. According to Oguntunde *et al.,* (2004), available phosphorus, exchangeable bases, total nitrogen, organic carbon and base saturation was higher in soils of charcoal production sites than the adjacent lands. A study conducted also showed that bulk density on charcoal-site soils reduced by 9% compared to adjacent field soils. Oguntunde *et al.,* (2004) observed that the grain and biomass yield of maize and also increased by 91 and 44%, respectively, on charcoal production sites soils as compared to adjacent farmland soil. The most significant impacts occurring during charcoal production and usage are emissions into the air and working environment. The pollutants emitted included green-house-gases, tars, NMVOCs (Non Methane Volatile Organic Compounds) and particulate matter. On the global and regional scale they contribute to the global warming, while on the local scale they may impose health risk for the workers and people living in the vicinity of production site (FAO, 2008). This process has direct linkages to negative social health outcomes. Lack of modern tools most often results in the use of human labor throughout the entire production process. In addition to the hazardous work conditions associated with the extraction of wood, building the kiln and packing the charcoal, doing so often constitutes a significant individual investment of time. Not including time spent during extraction and packaging, producers will often spend over two weeks vigilantly monitoring the kiln to ensure that the process of carbonization in the absence of oxygen, or pyrolysis, is properly conducted (Ribot, 1993). Extreme temperatures combined with volatile chemical compounds, including carbon monoxide and sulfur dioxide, create an extremely dangerous environment for any human, especially those without adequate safety protection. Producers are often known to spend the night within a few feet of a burning kiln to ensure that any gaps are quickly sealed. The United Nations Food and Agricultural Organization (FAO) released a working document highlighting the dangers associated with industrial charcoal production in the developing world and the precautionary measures that should be taken by producers (FAO, 1985). However, lack of proper knowledge, institutional capacity and financial resources prevents these safety measures from being taken in most areas that produce charcoal for residential use, contributing to the prevalence of moderate to severe injury and illness.

In the state of Mizoram in particular and the whole of north-east India in general, woodfuels constitute up to 80% of the total energy consumption and over 90% of the population of this north-eastern Himalayan region uses biomass as an important source of energy (Bhat and Sachan, 2004). According to Census of India 2011, Provisional Population Totals Paper 2, Volume II about 690 families in urban areas and 275 families in rural areas of Mizoram are still totally depend on wood charcoal as domestic fuel. In most of the regions, the population continues to rely upon traditional sources of biomass fuels, mainly charcoal and firewood to meet their energy needs. At the same time, charcoal is one of the most important fuel energy produced by the rural poor across Mizoram which is widely used in urban areas. Since, charcoal is a reliable, convenient and accessible energy source for cooking at all times and at a stable cost, the demand for charcoal in most of the regions continues to grow owing to the ever-increasing rural-urban migration. These trends coupled with inefficient charcoal production and consumption practices and inaccessibility by most households to other reliable and affordable commercial energy. Evaluation of fuelwood consumption rates and status of forest resources in the north-eastern Himalayan region has lead Bhat and Sachan (2004) to conclude that the estimated growing stock is unable to sustain the rate of fuel consumption in this region. The economy of over half of the population in Mizoram is entirely based on land and Jhuming / shifting cultivation is the mainstay of the people (Economy Survey Mizoram, 2008-09). As more than 80% of the forest land in Mizoram is owned by individual or community, the raw material is collected free of cost. Thus, charcoal business has flourished well in the state becoming a good income source among rural masses. Land tenure in many parts of Mizoram is particularly well organized. Customary land tenure are often exercise by the Village Council and by virtue of their authority, the village own lands are leased out to each families for a year for cultivation where they are allowed to produce charcoal from the felled trees, providing adequate land management practices and ultimately limited area.

The study area comprises of the whole of Mizoram state, covering all the 8 (eight) district headquarters *viz*., Aizawl, Kolasib, Serchhip, Champhai, Mamit, Lawngtlai and Siaha, and randomly selected villages representing each district to investigate the production and use pattern of charcoal. To study production and use pattern of charcoal, traders, wholesalers, major retailers and end users of wood charcoal in eight cities of district headquarters were identified and data on the charcoal industry as well as trade channel were collected by questionnaire of both close ended and open ended type. The components of the study were undertaken in sequence: first, the household survey of energy consumption; second the charcoal supply chain analysis; and finally the charcoal production survey. In this way, it was possible to follow the charcoal industry upstream from consumers, along the market chain and back to the producers.

The study was carried out during 2013 to 2016 throughout the state of Mizoram in which all the districts towns and selected villages are covered by conducting random questionnaire to selected respondents. The districts of Aizawl, Champhai and Serchhip were purposefully selected as these are the main charcoal dealing areas. Participant observations along the supply chain from the resource base up to the consumer in each towns and selected villages of the districts were interviewed, complemented by the use of questionnaires for all the stakeholders involved in the supply chain. Tools utilized in the field study were: Questionnaire survey for producers, transporters, middlemen, wholesalers /retailers, focus group discussions, personal interviews with key informants, entrepreneurs, intermediaries, service providers, government officials, and non-governmental organizations.

An extensive field survey was carried out in the state for a year. During the survey, observation was made on a number of variables. The primary data was obtained through semi-structured questionnaires and oral interviews with those respondents who have in depth knowledge and those involve in charcoal industry. A total of 480 questionnaires were distributed to all the sampled areas under study, comprising of separate questionnaire for each participants. Stratified sampling method was used in order to ensure comparability between each district capital and its surrounding rural areas. The study area was stratified into district wise, divided into two main components such as district capital area (trading and end use) and rural area (mainly production); 3 localities randomly selected from each 8 capitals and according to the extent of charcoal trade, 3 or more villages were selected from each districts.

However, to assess the quality attributes and charcoal produced and to evaluate the environmental impact of charcoal production sampling was carried out in Tualpui and Tualte village of Champhai district, Mizoram. Besides, to understand the indirect effect of charcoal production on soil, a poly pot experiment was further conducted to assess the growth and yield of selected agriculture crops in a poly house of Department of Horticulture and Medicinal and Aromatic Plants (HAMP), Mizoram University, Aizawl by collecting soil from the charcoal production and adjoining areas in Tualpui village of Champhai district, Mizoram.

Data on the species used, source, harvesting pattern, preprocessing, method of production, storage, post production handling, transportation and source of disposal were collected from identified traditional producers through pre-structured questionnaires prepared for the purpose. Tagged samples of the species used traditionally by the producers are converted to charcoal and their quality attributes are estimated. Similarly, the wood samples of same species are collected from the same area and the similar qualities are also tested in the laboratory for comparing with their carbonized state.

The field level carbonization experiments with 10 tree species included among the 24 tree species of the present study were carried out in kiln method. The size of the kiln was of medium size which is the most common size of kiln used by the charcoal producers in Mizoram. The 10 major tree species according to preference wise of varying girth were collected from the felled wood lot and cross-cut into logs of 1- 1.5m long. The logs were air dried and somewhat green, as preferred by the producers. The woods were hauled inside the kiln in an upright position and stacked in manner of species wise. To facilitate ignition, a kindling was placed at the ignition point and the fire was started. When the fire had caught after sometime, the opening was covered by earth-turf leaving a small hole opening for entering air.  Subsidence of combustion of the kindling on the kiln top (chimney) signaled completion of combustion. The charcoals were ready for collection after leaving in this state for 1 week. Then, the wood charcoals in species wise were carefully collected and packed in a separate container and ready for analysis.

All the activities and components in the charcoal production and use systems with potential impacts on environment have been described. Following the development of impact assessment sheets for each of these, the significance of these activities and components was qualitatively assessed and presented in figures and tables. As a result of this assessment the effects of some of these activities and components were excluded from further analysis while others were selected for an in depth assessment. There are seven activities selected for analysis of ecological effects, six belonging to the "charcoal production stage" and one belonging to the "charcoal use stage". Three activities were selected for the assessment of the health effects. In the case of assessment of economic effects, it turned out that the breakdown of the three major stages in the charcoal production system was too detailed. Therefore, aggregated assessments of the effects were used with respect to employment, income/expenditure and linkages to other economic activities under three titles: charcoal production, transportation, marketing and use. Pre-determined sample sizes were difficult to obtain given the informal nature of production and lack of available information on producer demographics. Using a snowball method, where subsequent respondents referred, surveys were conducted along the roadside of jhumlands as most charcoal production occurs along major jhumlands. The districts selected for this study were done so as a result of information gathered from stakeholder interviews; large-scale charcoal production is most prevalent within these locations.

Investigation of soil quality is one of the important factors for assessment of effect on environment by human activities. Therefore, impact of charcoal production on soil physico-chemical in comparison with soil properties of adjacent forest area were further deliberated to reveal the significance on environment. For this purpose, two sites of charcoal production were selected after intensive survey and recognition of charcoal production area *viz:* Tualpui and Tualte of Champhai district; where one site is of kiln method and another is pit method, respectively of the villages.

The composite soil samples from both the sites were collected from the depth of 0-15cm from 10 different sites of charcoal production and adjacent forest, followed by the removal of all unwanted materials. Each sample were kept and packed in a separate container and marked separately. The soil samples were air dried and sieved through a 2mm mesh and were subjected to laboratory for physical and chemical analysis. In order to assess the effect of charcoal production on soil; growth and yield parameters of selected agriculture crops were studied under poly house in the Department of HAMP, Mizoram University, Aizawl. Soils from different sites such as charcoal production site, adjacent forest soil and jhumland were collected from the study area of Tualpui village where there is a typical charcoal production by traditional kiln method. The collected soils were transported to the experimental site and filled in polypots of size 9.5” X 15.5” and labeling was done. The selected agricultural crops such as Tomato (*Lycopersicon esculentum* var.

Arka Rakshak F1 hybrid) and Bush beans (*Phaseolus vulgaris*) were grown in these pots, thus, making a design of two sets of experiment.

Charcoal production entails much strenuous work for the producer during felling, cross cutting, log haulage, kiln building and management. There are also risks associated with a carbonizing kiln particularly when repair work is being carried out. Accidents may occur which sometimes lead to death. Another health risk to the producer is the exposure to gases and smoke and also heat from the kiln. Of all the gases emitted, Carbon Monoxide (CO) is the major health risk. In order to understand the impact of charcoal production and utilization on health aspects, questionnaire survey was conducted and the response of the respondents was recorded and analyzed. The availability and status of raw materials of preferred woods and other resources for wood charcoal production were assessed through semi-structured questionnaire survey taking charcoal producers as the major respondents and the response were recorded and quantified. Accordingly, the data collected from different respondents were analyzed and presented with percentages and figures.

The study revealed that most trees used for charcoal production are sourced from producers' own jhumland and private; produced by using either traditional kiln or pit method of which the conversion efficiency are considerably low as compared to other methods from other advanced methods. In most of the districts, charcoal is mainly produced from individual jhumlands in conjunction to agricultural farming so that it serves as the additional income earning opportunity, whereas it was observed that charcoal is produced by a single person from private land in Mamit district. Major production of wood charcoal comes from Champhai district followed by

Serchhip district, in which the earliest commercial charcoal production was found to be started in 1992 from two villages identified *viz.* Kelkang and Dilkawn of Champhai district. The overall extensive production begins from around 2010. In general, more women were involved in charcoal trading than men in charcoal trading in most of the areas.

Even though almost all forms of wood could be used for charcoal certain kind of trees are preferred from others. A total of 24 species are recorded for charcoal production and 10 species are preferred by the respondents, at the same time other species are also utilized whenever there is no such preferred species are available. The most desired species are dense hardwood such as *Lithocarpus dealbatus,* followed by other *Lithocarpus sp* and *Quercus sp*.

The vast majority (99 percent) of charcoal producers in the study area employed the traditional earth kiln for commercial charcoal production, which was introduced by Japanese for wood vinegar production, but it was later modified for charcoal production. The peak season for charcoal business is during late October to early March, where the charcoal are shipped mostly by pick up and the demand is highest in Aizawl district where the tea stall/canteen contribute the highest usage. Most of the producing villages are located in remote areas with low grade link road, which become slippery and inaccessible for most of the vehicles, as such, the vehicles which can access during these adverse climatic conditions is pick up (Mahindra). Even those who own vehicle within the production villages usually have pick up as it can be employed for carrying goods and charcoal from their villages to the destinations throughout the year.

The charcoal quality experiment revealed that *L. dealbatus* has highest density and low friability which is considered desirable qualities in charcoal. The charcoal of *L. polystachyus* shows highest calorific value as compared to other species, which is an important attribute for the forging work; remarkably this particular species is preferred by blacksmiths. Pearson's correlation shows that charcoal moisture content is positively correlated with calorific value and ash content, but negatively correlated with friability. Similarly, bulk density is positively correlated with ash content whereas fixed carbon content is negatively correlated with volatile matters content.

In case of wood properties, the ash content and carbon content of wood is significantly correlated in negative. Those woods, which have more ash content possess less carbon content and *vice versa.* Correlation between wood and charcoal properties revealed significant that charcoal calorific value and wood calorific value are negatively correlated. Similarly, charcoal carbon content is positively correlated with moisture content and negatively correlated with wood calorific value.

All physico-chemical properties of *L. dealbatus* wood shows desirable quality in the experiment as well as locally preferred, thus it is ascertain that the particular species is preferred for charcoal making. The study observed that the wood land resources are experiencing an extensive degradation through the unsustainable methods of charcoal production. Apparently, there are changes in the vegetative biodiversity: gradually disappearing flora, yearly observed rainfall variability and complained reduction in farm yields among others. The study again identified that the traditional method of charcoal production adopted by charcoal producers as well as their preference for particular tree species are some of the key known factors destroying the vegetation. All interviewed charcoal producers, retailers and community leaders were strongly aware of the deteriorating rangelands and the negative effects of deforestation. About 100 percent of respondents expressed their knowledge about the declining tree populations in the vicinities of their town or villages. A smaller percentage of respondents were aware of the declining population of specific trees targeted for charcoal. Most respondents believed that the forests of the region will disappear, if the current unsustainable methods of land use continue, whereas fewer numbers thought that the forests will moderately or slightly decline. Most of the respondents felt that the raw materials are reducing, however, those villages situated near Forest protected areas seems to feel no change.

The overall public health of those engaged in charcoal have some complaint on physical injuries but health condition is less affected, in the meantime some of the respondents have no complaint at all. The effect of charcoal production on physical properties such as soil bulk density shows decrease in both kiln and pit method as compared to adjacent areas, meanwhile significant decrease is observed in pit method as compared with kiln method of production. Significant increase in water holding capacity is observed in the soils of charcoal production area in comparison to adjacent areas, within the method of production, pit method has higher water holding capacity. Clay is significantly increasing in charcoal production sites and pit method has higher fine particles than kiln method. Silt content is increase in both the charcoal production areas and the significant increase is observed in pit with kiln method. There is a highly significant decrease in sand percentage in charcoal production areas as compared to the adjoining areas. The soil from kiln method of production exhibit higher sand content as compared to pit method.

The study reveals that the effect of charcoal production and its method also varies on the soil chemical properties; carbon content in both the methods decreases significantly in charcoal production sites, whereas in pit method has significant higher content of carbon as compared to kiln method. Nitrogen is found to be significantly increased in charcoal production area than adjoining site in kiln method, while the reverse is in pit method, which shows that more nitrogen deposition is observed in kiln method but not significant. Available phosphorous is significantly increased in both the production sites of the two methods, the pit method significantly produced more nitrogen than kiln method. As for magnesium, there is increase in production site in both the methods; however, kiln method is significantly higher in comparison to pit method. Increase in sodium is also observed in both the production sites and more amounts are also noted in pit method. Charcoal production sites contain more amounts of potassium and calcium as compared to their respective adjoining areas, in the meantime kiln method of production is observed to be produced more than pit method. Due to the increase in particular bases, cation exchange capacity is also subsequently increases in production sites, comparing the methods, kiln method has significantly higher capacity than pit method of production. However, electrical conductivity is lower at production areas in both the method, significantly higher in pit method. Charcoal production area in both the method show significant increase in exchangeable acidity, also significantly higher amount is observed in pit method. The pH in both the charcoal production sites increases significantly and even highly significant increase is observed in kiln method in comparison to pit method.

Thus, the experiment on cultivation of agricultural crops in controlled environment shows that the growth and yield of both bush beans and tomatoes shows significant augmentation in all the parameters tested, except the height and number of leaves in case of beans.

Many people in the north-eastern region of India including the state of Mizoram are engaged in charcoal production on commercial scale which is probably due to the vegetation and availability of raw materials of the preferred dense hardwood. The charcoal producers rely on natural regeneration of the preferred tree species, which is supplemented with long rotation period of trees, consequently the availability of these particular species are observed to be declining.

The prevailing system of jhum cultivation is coexist with charcoal production, proper land use management techniques, increase wood supply through agroforestry/afforestation, along with utilization of high efficiency kilns can significantly lower the impacts associated with charcoal industry and may take away the pressure from natural forests and could even become a stable source of income for producers.

Charcoal production is still practice at the household, informal level; as a result there is no regulatory framework in place to regulate charcoal production, distribution and sales in the state, which is affecting the environmental aspect of our economy. Therefore there is a need to establish a legal regulatory framework spelling out the coordination mechanism among various stakeholders in the charcoal industry. There is also need to support charcoal businesses as part of the small-and-medium scale enterprise development in the country since such business have been found to be an important source of income to many households. The use of traditional tools, combined with heavy lifting, exposure to high temperature, inhalation of particulate matter during combustion leads to common injuries and sickness as mentioned by several respondents. Therefore, creation of awareness on health impacts of inhaling charcoal dust and other particulate matter is compulsory advisable. The creation of public awareness on energy efficiency and conservation practices and health impacts in the use of charcoal is also necessary.

Adopting modern methods and technology may improve production and utilization and also may reduce the health risks associated with charcoal production. Besides charcoal quality of less preferable species may also be improved. Therefore, providing logistical support for the concern department to expand technical assistance and the creation of awareness on the adoption of improved carbonization technologies to charcoal producers.

The effect of charcoal production on soil seems to be significantly benefitting agricultural crop production which is due to improvement in soil physical and chemical properties by the enrichment of soil nutrients with biochar and its constituents.

Charcoal industry is economically valuable, but it has adverse effect on environment in terms of surrounding forest resources of the rural poor who offer the benefit of cheap and reliable fuel to their urban counterparts. Most of the people interviewed were not aware of the linkages between the charcoal production and the global environment. Besides reducing the carbon stored in the forests and releasing emissions during the burning process, charcoal production and consumption also causes reduction of the forest cover, biodiversity and environmental services threatening the resources' sustainability as well as causing health problems. Looking at current consumption patterns, it is important that the different stakeholders take actions to solve the problem and avoid future environmental problems. Options to tackle this problem include: i) dissemination of improved production technologies such as the drum kilns, ii) introduction of stoves with improved efficiency, iii) provision of affordable alternative energy sources and iv) the introduction of fast growing species and agricultural wastes for charcoal production. Awareness raising campaigns for all stakeholders involved in the supply chain are needed. Furthermore, the forest should be replenished through agro-forestry carefully guided by research to identify suitable trees with shorter gestation periods.

The yield of charcoal also shows some variation with the kind of wood. The mature wood in sound condition is preferred for charcoal production. Dense wood also tends to give a dense, strong charcoal, which is also desirable. However, very dense woods sometimes produce a friable charcoal because the wood tends to shatter during carbonization. The friability of charcoal increases as carbonization temperature increases and the fixed carbon content increases as the volatile matter content falls. It is recommended that a temperature of 450 to 500°C gives an optimum balance between friability and the desire for a high fixed carbon content.

There is thus a need to encourage diversification and the use of plantation species or species producing less dense charcoal. While less dense charcoal may have different physical properties, there is no difference in energy terms. Although dense charcoal does indeed hold more energy by volume, this is not the case by weight. Where the use of alternative species for charcoal making is promoted, it is necessary to re-evaluate the processes involved in the charcoal production and utilization chain. One necessary adaptation is the design of energy-efficient charcoal stoves, as most of the stoves currently used are not really suitable for charcoal from lightweight species, burning it too quickly and vigorously for consumers' needs.

As charcoal commodity is moved from the point of production through markets to consumers, it incurs various costs: production, transportation, taxation and other informal costs. Thus, it is problematic to accurately present the cost benefit distribution of the business along its chain. What is obvious at this point is that the current charcoal production system does not take the tree resource into account. This is mainly because charcoal makers produce charcoal from state or communal forest resources free of charge.

There is also need to support charcoal businesses as part of the small-and-medium scale enterprise development in the state since such business have been found to be an important source of income to many households. Therefore, an organized market through govt. supported agencies (such as cooperative societies) with proper trade regulation may benefit the poor charcoal producers in these remote areas to provide technical assistance and funding for programmes to transfer improved carbonization technologies and higher levels of efficiency in the production, distribution and use of charcoal. Strengthen through technical assistance existing institutions for testing and certification of improved production and end use technologies for charcoal.