COMPARATIVE STUDY OF GROWTH AND PRODUCTIVITY OF MAIZE (*Zea mays* L.) UNDER DIFFERENT JHUM CYCLES OF MIZORAM

THESIS
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By

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CERTIFICATE

This is to certify that the thesis entitled " *Comparative Study of Growth and Productivity of Maize (Zea mays L.) Under Different Jhum Cycles in Mizoram*" submitted by Mr. Lalrammuanpuia Hnamte for the degree of Doctor of Philosophy in Forestry embodies the record of original investigation carried out by him under my guidance and supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D degree. This thesis or any part thereof has not been submitted for any degree of any other University.

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DECLARATION

I, Mr. Lalrammuanpuia Hnamte, hereby declare that the subject matter of this thesis is the record of the work done by me, that the contents of this thesis did not form basis for the award of any previous degree to me or to anybody else, and the thesis has not been submitted by me for any research degree in any other University/ Institution.

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

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LIST OF ABBREVIATIONS USED

°C	:	Degree Celcius
%	:	per cent
cm	:	centimeter
E	:	East
Ed: (eds.)	:	Edition: editor(s) or edited
et al.	:	et alii: and others
etc.	:	etcetera or cetera: and the others
g/gms	:	gram(s)
ha	:	hectare
K	:	Potassium
m	:	metrum: metre
mg	:	milligram
mm	:	millimetrum: millimeter
ml	:	milliliter
N	:	North / Nitrogen
no.	:	numero: number
p., pp.	:	pigina: page, pages
P	:	Phosphorus
qt	:	quintal
sp., spp	:	species (singular); species (plural)

Chapter – I

INTRODUCTION

1.1 Global Agriculture production

Agriculture is the world’s largest use of land, occupying about 38% of the Earth’s terrestrial surface. The agricultural community has had tremendous successes in massively increasing world food production over the past five decades and making food more affordable for the majority of the world’s population, despite a doubling in population (Dobermann and Nelson, 2013).

Approximately 790 million people in developing countries are described as undernourished, with Sub-Saharan Africa highlighted as the region with the greatest hunger (<1260kJ/ day) affecting 180 million people (FAO, 2002). Even more troubling is the fact that thousands die daily as a result of diseases from which they likely would have survived had they received adequate food and nutrition (Craig D. Idso, 2011). The number of undernourished increased in the rest of East Asia (excluding China) and even more in the rest of South Asia (excluding India) (FAO 2006).

By 2025, continuing population growth and current agricultural practices will lead to 36 more countries (pop. 1.4 billion) falling into the category currently occupied by 21 countries (pop. 600 million) where either good cropland or fresh water are scarce (National Intelligence Council. 2008). Credible research already makes it clear that there is a growing depletion of the key natural resources, including land, water, and biodiversity, that are fundamental for sustainable production. No human endeavour uses more of these resources than agriculture. (OECD, 2011).

Of the world’s 1.1 billion extremely poor people, about 74 % (810 Million) live in marginal areas and rely on small scale agriculture. While the world currently produces enough food to feed everyone, at least one billion people remain food insecure (FAO, 2010). Although the incidence of hunger dropped from a ratio of one in three in 1960 to affecting roughly one in seven people by the 1990s, the trend reversed in the 1990s and the absolute number of people blighted by hunger continues to grow. In 2009, for the first time in history the population considered to be malnourished exceeded one billion people Sub-Saharan Africa has the highest proportion of undernourished people, 30 percent in 2010, while the Asia Pacific region has the most undernourished people (578 million) according to the FAO. Two thirds of the world's undernourished live in just seven countries – Bangladesh, China, the Democratic Republic of Congo, Ethiopia, India, Indonesia and Pakistan (FAO, 2010).

It is also estimated that by 2050 another 2.3 billion people will be added to the current population of 7 billion, with most of this increase happening in countries that are home to significant numbers of people suffering from food insecurity, malnutrition, and extreme poverty (2010 Revision of World Population Prospects. U.N. Population Division of the Department of Economic and Social Affairs).

The Green Revolution made available a package of biochemical inputs (HYVs, fertilizer and irrigation) that promised to be scale neutral and thus raise the yields and incomes of all farmers and substantial Government subsidies allowed increased production through crop intensification (Bernstein *et al.,* 1992). While there is little doubt that the Green Revolution enabled massive increases in yields and the achievement of self-sufficiency in grains for India, it had a very uneven impact on regions, crops, and individuals (Lipton and Longhurst, 1989). Rural people take part in a number of strategies, including agricultural intensification, migration and livelihood diversification, which enable them to attain a sustainable livelihood (Tiffen *et al.,* 1994).

Productivity increase has been particularly strong in developing countries, and especially for cereals such as rice in Asia, wheat in irrigated and favourable production environments worldwide, and maize in Mesoamerica and selected parts of Africa and Asia (Pingali and Heisey, 2001). Most of the world irrigated agriculture today is in developing countries. Nearly one half of the irrigated area of the developing countries is in India and China. Food consumption, in terms of kcal/person/day, is the key variable used for measuring and evaluating the evolution of the world food situation (Alexandratos and Bruinsma, 2012). Food production is particularly sensitive to climate change, since crop yields depend in large part on climate conditions such as temperature and rainfall patterns (Stern, 2007).

The increased food production will also have to occur on less available arable land and this can only be accomplished by intensifying production which must be done in an environmentally safe manner through ecological intensification. Commercial fertilizer is responsible for 40% to 60% of the world’s food production. So, effective and efficient use of fertilizers is very important to increase the supply of food demand (Roberts, 2009).

Future word populations will require ever-increasing food supplies. The availability of food per capita has been declining for nearly two decades, based on available cereal grains. Cereal grains make up 80% of the world's food. Although grain yields per hectare in both developed and developing countries are still increasing, these increases are slowing while the world population continues to escalate (PRB, 2002). Although agricultural productivity has generally increased globally, it has hardly kept the pace with population growth. In much of the developing world, population growth has negatively impacted food security. (Ramankutty *et al.,* 2002).

Grains such as rice, wheat, and maize account for about half of human caloric intake (FAO. 2002). About half of the world's grain is now used to produce animal feed and animal consumption is projected to double between 2000 and 2050 (Steinfield *et al.,* 2010). A change in the availability of grains has an effect on the food available for a large part of the human population (Yotopoulos, 1985). The vast majority of the world's farmers are smallholders and small farms are at risk. A trend toward the dominance of larger farms is occurring in some countries even as fragmentation and population growth is leading to ever smaller and perhaps unsustainable farms in others.

Agricultural growth contributes directly to food security. It also supports poverty reduction. The population increase, combined with moderately high income growth, could result in a more than 70% increase in demand for food and other agricultural products by 2050. Much of this growth originated in developing countries (3.4 – 3.8 percent p.a.). Even though the value of total agricultural output per capita has had a yearly growth of 0.6% p.a. since 1961, not all regions have followed the same trend (Wik *et al.,* 2008).

A trend of increasing urbanization is detected worldwide (Mitlin, 2005) which is proceeding at a high pace is an important factor influencing consumers' preferences (MEA, 2005). This affects food consumption patterns in a number of ways (Regmi and Dyck, 2001). Globally, urbanization is expected to double the proportion of urban residents to the total population, reaching nearly four billion by 2020 and affecting mainly developing countries (Haddad *et al.,* 1999; Regmi and Dyck, 2001). Global trade in food and feed crops has accelerated over the period (Galloway *et al.,* 2007) and higher income levels are associated with a greater demand for more expensive sources of calories, such as meat, fruit, vegetables, and processed food products (Seale *et al.,* 2003)

1.2 INCREASE IN AGRICULTURAL LAND AND ITS EFFECTS ON DEFORESTATION

Forests cover almost one third of the earth's land surface providing many environmental benefits including a major role in the hydrologic cycle, soil conservation, prevention of climate change and preservation of biodiversity (Sheram, 1993). Deforestation including clearing for agricultural activities is often the only option available for the livelihoods of farmers living in forested areas (Angelsen, 1999). A global move to sustainable agriculture for sustainable development is clearly vital (Munasinghe and Swart, 2005). Land conversion from forests to agriculture and pasture has been associated with climate changes at the global scale (Fearnside, 1996). While developed countries have contributed to much of the planet's recent warming trend by burning fossil fuels and via the introduction of industrial compounds. Adger and Brown (1994) estimated that tropical deforestation is responsible for between 25% and 30% of the purported climate warming in the world; and forests are responsible for about 90% of the carbon stored in global vegetation (Dale, 1997). Furthermore, climate change is believed to affect world food supply and productivity (Brown, 1994).

The practice of jhum cultivation is reported to account for 60% forest losses worldwide each year (Lele *et al.,* 2008). The ever increasing population has created tremendous pressure on land to provide basic requirement for survival. To meet these requirements, the limited natural resources are being over-exploited resulting in widespread ecosystem degradation (Grogan *et al.,* 2012). Grazing land and land for crops to feed animals, makes up 80% of all agricultural land – 3.4 billion hectares for grazing and 0.5 billion hectares for feed crops (FAO, 2009). Forests are often cleared to make space for this grazing and feed crop land; over the last 25 years, the world has lost forests equal in size to India (FAO, 2006).

The impacts of population pressure on land degradation may be mixed. Land degradation may increase as a result of cultivation on fragile lands, reduced use of fallow, increased tillage, mining of soil nutrients, and other potential results of intensification. On the other hand, investments in land improvements and more intensive soil fertility management practices may improve land conditions (Pender, 2001; Tiffen *et al.,* 1994; Scherr and Hazell, 1994).

It is generally agreed that agricultural impacts will be more adverse in tropical areas than in temperate areas (Parry *et al.,* 2005; Fischer *et al.,* 2005), and that climate change effects will likely widen the gap between developed and developing countries. Low levels of warming in temperate areas (US, Europe, Australia and some parts of China) may improve the conditions for crop growth by extending the growing season and/or opening up new areas for agriculture. But further warming will have increasingly negative impacts, as damaging temperature thresholds are reached more often and as water shortages limit crop growth in semi-arid regions such as Australia, Southern Europe and Western USA (IPCC, 2007).

Deforestation is primarily a concern for the developing countries of the tropics (Myers, 1994) as it is shrinking areas of the tropical forests (Barraclough and Ghimire, 2000) causing loss of biodiversity and enhancing the greenhouse effect (Angelsen *et al.,* 1999). The relationship between development and deforestation is complex and dynamic (Sands, 2005; Humphreys, 2006). Deforestation is the conversion of forest to an alternative permanent non-forested land use such as agriculture, grazing or urban development (Kooten and Bulte, 2000). Rowe *et al.,* (1992) estimated that 15 per cent of the world's forest was converted to other land uses between 1850 and 1980. Deforestation occurred at the rate of 9.2 million hectares per annum from 1980-1990, 16 million hectares per annum from 1990-2000 and decreased to 13 million hectares per annum from 2000-2010.

Indeed, it is feared that agricultural expansion which is the main cause of deforestation in the tropics might replace forestry in the remaining natural forests (Anon., 2002; Cossalter and Pye-Smith, 2003; Anon., 2005). The impact of timber plantations could thus turn out to be quite detrimental to tropical forest ecosystems (Kartodihardjo and Supriono, 2000). Based on the data available from 118 countries representing 65 per cent of the global forest area, an average of 19.8 million hectares or one per cent of all forests were reported to be significantly affected each year by forest fires (Anon., 2010). Although small farmers and shifting cultivators are not the main drivers of deforestation in regions where most deforestation takes place, they do contribute to it. In the long run, reducing their impacts on deforestation might be more difficult than reducing deforestation from large-scale commercial agricultural or logging operations (Shearman *et al.,* 2009). On the other hand, it may be more difficult to develop the new systems that ensure small farmers and shifting cultivators retain their livelihoods without additional deforestation.

Expanding cities and towns require land to establish the infrastructures necessary to support growing population which is done by clearing the forests (Sands, 2005). Tropical forests are a major target of infra-structure developments for oil exploitation, logging concessions or hydropower dam construction which inevitably conveys the expansion of the road network and the construction of roads in pristine areas (Kaimowitz and Angelsen, 1998). The demands of urban populations lead to farmland expansion in rural forested areas to produce more crops, which impact forest conversion for agriculture and lead to deforestation (Carr *et al.,* 2006). Agricultural land expansion is generally viewed as the main source of deforestation contributing around 60 per cent of total tropical deforestation (Wilkie *et al.,* 2000; Amor, 2008; Amor and Pfaff, 2008). Increasing agricultural yields has been the predominant mode for increased food production for the last several decades, but intensification can also lead to more deforestation in some circumstances (Rudel *et al.,* 2009;Boucher *et al.,* 2011).

Research published in 2012 estimates that agriculture is estimated to be the direct driver of 80% of the world's deforestation. According to the Millennium Ecosystem Assessment (MEA), the most important drivers of biodiversity loss are habitat change, climate change, invasive alien species, overexploitation, and pollution. These include the clearing of land for crops and the use of fossil fuel-based and often toxic pesticides and fertilizers that pose risks to human health and wildlife populations. (Brighter Green and GFC, 2013).

Most of the causes of deforestation, including logging, land conversion to agriculture, wildfires, cutting down trees for firewood, and conflict over land rights tend to be caused by increased population growth and a need for more land mostly for agricultural production (Johnson and Chenje, 2008). The highest rates of deforestation (in 106 ha/yr during the 1990s) occurred in Brazil (2.317). India (1.897), Indonesia (1.687), Sudan (1.003), Zambia (0.854), Mexico (0.646), the Democratic Republic of the Congo (0.53; b7b8), and Myanmar (0.576) (FAO, 2001).

Ecological research is leading to new understanding of agro-ecosystem function that is enabling yield growth through improved nutrient cycling, water utilization, improved pest and disease management, nitrogen fixation, and synergistic plant interactions (IAASTD, 2010). The World Resources Institute estimates that only about 22% of the world's (old growth) original forest cover remains "intact". Slash-and-burn techniques are used by native populations of over 200 million people worldwide. Thus, solutions to deforestation must include and benefit local communities. Community forestry involves a group of people practicing sustainable management of forests; social and economic benefits to them are a central goal. Intensification of small-scale agriculture can also reduce agricultural expansion into forested areas if the correct incentives are in place (Palm *et al.,* 2010).

Jhum cultivation is considered as a major driver of deforestation. Globally, until the year 1991, jhum had accounted for 61% of overall tropical forest destruction (Myers, 1991). Nevertheless, the practice persists since it provides subsistence livelihoods to at least 300 to 500 million people worldwide (Brady, 1996) and is intricately linked to cultural, ecological, and economic aspects of communities (Ramakrishnan, 1992). While certain ecologists question the sustainability of the practice, since it involves clearing of primary and secondary forests, others appreciate the existence of the practice for several millennia and acknowledge the fact that timber-felling, monoculture plantations (Dressler, 2005; Ickowitz, 2006) and other such economic-oriented objectives are also critical drivers of deforestation. However, when fallow cycles drop below a critical time period due to increased human population leading to unavailability of land, the productivity of the plot as well as forest regeneration are negatively affected (Raman et al, 1998). The density of human population jhum can sustain is 7 km^{-2}, which is considerably lower than present densities in Jhum landscapes in the tropics (Whitmore, 1984).

1.3 JHUM CULTIVATION

Jhum cultivation is one of the most ancient system of farming (Borthakur, 1992) believed to have originated in the Neolithic period around 7000 B.C. (Spencer, 1966). The system is regarded as the first step in transition from food gathering and hunting of food production. It is practiced in different parts of the world. It is a multifaceted form of agriculture has been widely practiced by hill communities in Asia, Africa, and Latin America since 13,000 to 3,000 B.C. (Mazoyer and Roudart, 2006). The cropping system encompasses horticulture, annual/perennial crops, animal husbandry and management of forests and fallows in sequential or rotational cycles (Thrupp *et. al.*, 1997).

In the Jhum system of cultivation a piece of forest land is slashed, burnt and cropped without tilling the soil, and the cropped land is subsequently fallowed to attain pre-slashed forest status through natural succession (Uhl *et al.,* 1983; Ramakrishnan, 1993). It is an old-age practice among the tribal groups throughout the tropic- the Amazon basin, Southeast Asia and Sub-Saharan Africa. It is largely viewed as an exploitative system, where the land and natural resources are not managed.

The cultivation, typically involves clearing the land, burning much of the plant material, planting and harvesting crops, and then abandoning the land for fallow and moving to new plot of land. During the fallow period, the forest vegetation re-grows and can be re-burned at a later date, adding nutrients to the soil for future cropping (Teegalapalli *et al*, 2009). The intervening period for which a jhum land is abandoned is known as jhum cycles (Bam, 2015). It is called by different names in different parts of the world. It is generally known as 'slash and burn' and 'bush fallow' agriculture. It is variously termed as Ladcmg in Indonesia, Caingin in Philippines, Milpa in Central America and Mexico, Ray in Vietnam, Conuco in Venezuela, Roca in Brazil, Masole in the Congo and Central Africa (Priyadarshni, 1996).

Jhum cultivation is the key to the livelihoods of many ethnic, indigenous and tribal groups in the tropical and sub-tropical regions (Andersen *et al.,* 2008). In many places in the tropics, traditional jhum cultivation is practiced by indigenous peoples who have inhabited remote forest areas for a long time, whereas migrant farmers living at the forest edge may be practicing small scale slash-and-burn-agriculture without incorporating long fallow periods (Sanchez *et al.,* 2005). The practice of jhum is not, merely exercised by the tribals for their sustenance, but a traditional method of earning a livelihood, a traditional farming system that uses local product and techniques, has rooted in the past, has evolved to their present stage as a result of the interaction of the cultural and environmental condition of the region and is deeply embedded in the tribal psyche (Gupta, 2005).

1.4 JHUM CULTIVATION – GLOBAL SCENARIO

Throughout the world there are about 70 million people living in remote tropical forests (Chomitz *et al.,* 2007). Across South and Southeast Asia a large number of people depend for their livelihood and food security fully or partly on jhum cultivation. The actual number of these people is not known. The number of jhum cultivators in Southeast Asia has been estimated to lie between 14 and 34 million people (Mertz *et al.,* 2009).

Jhum cultivation is probably one of the most misunderstood and controversial forms of land use. In 1957, the FAO declared jhum cultivation the most serious land use problem in the tropical world (FAO, 1957). The majority of the people practicing jhum cultivation in South and Southeast Asia belong to ethnic groups that are generally subsumed under categories like ethnic minorities, tribal people, hill tribes, aboriginal people or Indigenous Peoples (Erni, 2008). In South Asia, this cultivation is practiced particularly by Adivasis in Central and South India and by indigenous peoples in the Eastern Himalayas, i.e. Eastern Nepal, Northeast India, the Chittagong Hill Tracts of Bangladesh and the adjacent areas across the border in Myanmar. In mainland Southeast Asia, jhum cultivation has until very recently been the predominant form of land use in all the mountainous areas. The same holds true for the remote interior and uplands of Insular Southeast Asia (Cramb *et al.,* 2009).

Jhum cultivation throughout the tropics is largely a subsistence activity practiced in areas with few alternative options and is therefore a practice that is likely to continue. Secondary forests formed following logging and jhum cultivation covers more than 600 million hectares and play an important role in biodiversity conservation in the tropics (Brown and Lugo, 1990). Since jhum cultivation in the tropics is mainly practiced on nutrient-poor soils, forest vegetation re-growth and re-burning is important for crop growth. Furthermore, weed, pest, and crop disease populations decline. Fallow periods in a jhum cultivation system vary and can be long enough for forests in abandoned plots to regenerate. The cultivation can imply a diverse set of farming practices, and in some cases fallow land is partially planted with tree crops for subsistence use or additional income. Many jhum cultivators are semi-subsistence and small-scale farmers in tropical rainforest areas (Mertz *et al.,* 2009; Hassan *et al.,* 2005; Giller and Palm, 2004).

Nearly in the past ten years, fewer jhum cultivators can allow for long fallow periods and regeneration of forests because they do not control large enough areas due to population densities, political pressures, and economic demands in tropical regions. The historical system of jhum cultivation, which can be sustainable in areas with low population densities and large land areas, is rare and has mostly been supplanted by agricultural intensification (Chomitz, 2007; Sanchez *et al.,* 2005).

Small-scale farmers cultivate many types of crops depending on the region. For tropical regions broadly, some of the most important cereals grown for food include grains like rice, maize, sorghum, and millet. Cassava, sweet potatoes, and bananas are also important foods (Norma, Pearson, and Searle 1984). Women play a major role in small-scale agriculture, particularly in Sub-Saharan Africa, where they make up the majority of farmers. (Mehra and rojas 2008; World Bank, 2007).

In many parts of Southeast and South Asia, jhum cultivators are currently confronted with a resource crisis as the population-land ratio has reached critical levels. Population growth, caused by natural growth and spontaneous in-migration and resettlement, is however only one of its causes (Cramb et al., 2009). Government restrictions on jhum cultivation and large-scale alienation of Indigenous Peoples' land have in many cases been the main cause of land scarcity. However, against predictions by concerned policy makers and environmentalists, the crisis did not lead to collapse and shifting cultivators have adapted by modifying their livelihood and land use practices (Padoch, *et al.,* 2007).

There are underlying reasons for the actions of small farmers and jhum cultivators. Road and infrastructure development in tropical forest regions has given migrant farmers access to previously inaccessible forest areas. In some regions, poverty-driven deforestation can occur if small-scale and subsistence farmers lack resources or secure land tenure and are forced to move into forested areas to grow food and earn their livelihoods (Sanchez *et al.,* 2005; geist and lambin 2002).

Small-scale subsistence farmers with little connection to markets deforest less, highlighting the importance of commercial markets and urban and international demand as underlying causes of deforestation (deFries *et al.,* 2010; Pacheco, 2009). In the past seven years, government-sponsored colonization programs facilitated the movement of landless migrants to the frontiers of tropical forests (Sanchez *et al.,* 2005; Rudel *et al.,* 200;). In the 1960s and 1970s, the cold war and the Cuban revolution encouraged rural movements for land reform in Latin America and

Southeast Asia. Governments responded with colonization programs to provide small farmers with land in remote forested regions, since this was easier than taking land away from large farmers. In order to help this colonization effort, governments built roads into rain forests. With the fall of the Soviet union and the end of the cold war, this motivation for state-initiated deforestation disappeared (Rudel *et al.,* 2009).

The international policy known as redd+ (reducing emissions from deforestation and forest degradation, plus related pro-forest activities) can place value on standing forests and provide economic incentives for (a) reducing carbon dioxide emissions resulting from deforestation and (b) increasing sequestration of carbon through forestry practices. In these programs, establishing land tenure and other entitlements for small farmers, indigenous peoples, and other stakeholder groups such as women is important for the inclusion of small farmers in a redd+ system. Such international policies can benefit jhum cultivators and small-scale farmers if structured correctly and equitably (Mertz, 2009).

In many parts of Southeast and South Asia, shifting cultivators are currently confronted with a resource crisis as the population-land ratio has reached critical levels. While natural growth of local populations has contributed to increasing land scarcity, state-sponsored or spontaneous in-migration and resettlement are the more common cause (Cramb *et al.,* 2009). Fox *et al.,* (2009) have identified six external factors that contribute to the profound transformation or complete replacement of jhum cultivation:

1. Classifying shifting cultivators as ‘ethnic minorities’ in the course of nation building, and the concomitant denial of ownership and land-use rights;

2. Dividing the landscape into forest and permanent agriculture, the claim over the former by forest departments and the transfer of use rights to logging companies and commercial plantations;

3. The expansion of forest departments and the rise of conservation, which have further expanded and strengthened state control over forests;

4. Resettlement of shifting cultivators out of upland and forest areas and the dispossession of their lands as a result of the non-recognition of collective or individual rights over land and forests;

5. Privatization and commoditization of land and land-based production, resulting in dispossession of shifting cultivators and giving rise to commercial agriculture and industrial tree-farming by private companies, state enterprises as well as entrepreneurial farmers and small-holders;

6. Expansion of infrastructure (roads, electricity, telecommunication) and subsidies for investors supporting markets and promoting corporate and private industrial agriculture.

It is too obvious that there are simply not enough resources for all countries to become as industrialized and reach the level of consumption of natural resources as Europe or the United States. According to Tudge (2005), “Only agriculture can employ the vast numbers of people who need employment. Only agriculture can do so sustainably.” Thus, many people will continue to directly live off the land, indigenous peoples in particular.

Urbanization and population pressure are the two most important threats to biodiversity worldwide and their growth affected natural resources. Urban area may make threats ecosystem through direct habitat conversion (Clergeau *et al.,* 1998; McKinney, 2002) and through various indirect effect of human population pressure like resource use, habitat fragmentation, waste generation and fresh water cooption (Mikusinski and Angelstam, 1998). Understanding the complex mechanism of biodiversity necessitates its spatial and temporal dynamics management of landscape and synergetic adoption of measurement approaches with long-term plot inventories are imperative (Yadav *et al*., 2012).

Due to increase of population density many kind of precursor, both social and environmental, appears in habitat. One environmental precursor is pollution, the effect of which in forest ecosystem studied by many investigators (Bormann and Likens, 1979). The other is population pressure which is caused by excessive increase in population density in forest habitat leading to argumentation of industrialization and consumption of natural resources for livelihood. Increasing human intervention and excessive exploitation of resources have resulted in great changes and provide alarming signals of accelerated biodiversity loss (Yadav *et al.,* 2013). The impact of population growth on environment is significant because each person make same demands on natural resources for the essential of life-food, water, clothing, shelter and so on.

1.5 JHUM PRACTICE IN INDIA

About 10 million hectare of tribal land stretched across 16 states estimated to be under jhum cultivation in India (Eswaraiah, 2003) which is about 0.32 percent of total geographical area. On an average, estimated 38.69 thousand hectare area is set under this type of cultivation every year (Tripathi and Barik, 2003) and nearly 600,000 families are involved in jhum cultivation all over India (Keitzer, 2001). There are varieties of livelihood practices by the tribal communities in different parts of India and elsewhere, such as the hunter-gatherers, pastoralist and jhum cultivators who live in different environments. Many changes have been taking place with regard to land use, access, control and utilization of their resource and these changes in turn have largely affected the sustainable livelihoods of the people without emphasizing sustainable replacement (Shivaprasad and Eswarappa, 2007).

In India, Green Revolution started in the 1960s based on use of commercial fertilizer and pesticides along with novel crop strains developed using genetics and biotechnology (Mooney et al., 2005), has made the country self sufficient for nourishing the growing populations. However, this agricultural intensification has negative impact on the soil fertility and thus there is a plateau formation in Indian agriculture production. Maintenance of soil organic matter is a major problem in sustained high crop production practices and environmental contamination in Indian agriculture (Kushwaha *et al.,* 2000, 2001; Kaufman and Watanasak, 2011).

This cultivation practice has different names in India. It is known as Jhum in the hilly states of Northeast India, as Podu, Dabi, Koman or Bringa in Orissa, as Kumari in Western Ghats, as Watra in southeast Rajasthan, as Penda, Bewar or Dahia and Deppa or Kumari in the Bastar district of Madhya Pradesh (Priyadarshni, 1996). Indian Agricultural sector has been undergoing astonishing changes since 1950s. The record production of food grains from 50 million tons in 1950 to 241 million tons in 2009-10 is hailed as a breakthrough in Indian agriculture (Anonymous, 2011).

In India, the people of eastern and north-eastern region practice jhum cultivation on hill slopes. 85% of the total cultivation in northeast India is by jhum cultivation (Singh and Singh, 1992). Due to increasing requirement for cultivation of land, cycle of cultivation followed by leaving land fallow has reduced from 25–30 years to 2–3 years. Earlier the fallow cycle was of 20–30 year duration, thereby permitting the land to return to natural condition. Due to reduction of cycle to 2–3 years, the resilience of ecosystem has broken down and the land is increasingly deteriorating (Patro and Panda, 1994). The degree of soil degradation depends on soil's susceptibility to degradative processes, land use, the duration of degradative land use, and the management. Soil and water degradation are also related to overall environmental quality, of which water pollution and the greenhouse effect are two major concerns of global significance. Recent global concerns over increased atmospheric CO_2, which can potentially alter the earth's climate systems and have resulted in raising interest in studying soil organic matter (SOM) dynamics and carbon (SOC) sequestration capacity in various ecosystems (Schlesinger, 1999).

1.6 JHUM CULTIVATION IN NORTH EAST INDIA

Geographically, North East (NE) India stretches between 21°50' and 29°34' N latitude and 85°34' and 97°50' E longitude. This region is covering a geographic area of 2,55,143 sq km and holding a population of 38 million, which are 8% and 3.85% of area and population of whole India, respectively. Most marked characteristics of this region are large rural population (89.86%), huge tribal inhabitants (Irshad Ali and Das, 2003) and wide area covered under forests (63.9%) (Mishra and Sharma, 2001). The region is characterized by diverse agroclimatic and geographical situations (Borthakur, 1992).

"Jhum", a shifting agriculture technique pertaining to North-Eastern Region of India (NERI) is traditionally being practiced by local tribes from ancient ages (Deka and Sarma, 2010). The North Eastern Region comprises the contiguous seven sister States (North-east India) - Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland Tripura and the Himalayan state of Sikkim. In all of north-east states, an estimated 1466 thousands hectares of land are under jhum cultivation (Yadav, 2013) which contributes 85% of the total cultivation in Northeast India. About 26,000 households practice Jhum cultivation every year and nearly 143,000 people depend on it for subsistence (Shoaib, 2000). In fact, whole of NERI can be appropriately termed as the land of jhum cultivators and the cultivation area practiced in this region is nearly 19.91 lakh ha and it is approximately 83.73% of the total jhum cultivation area in India (GOI, 2000; Mandal, 2011). It has evolved as a traditional practice and is an institutionalized resource management mechanism ensuring ecological sustainability and food security thus providing a social safety net for local communities (Andersen *et al.,* 2008).

Jhum cultivation is a unique feature of agriculture in the hilly region of NE India. Although, this practice is criticized due to low productivity and environmental diseconomies; continuance of jhum cultivation is closely linked to ecological, socio-economic, cultural identity and land tenure systems of tribal communities (Deka and Sarmah, 2010). The low productivity is due to many limitations viz. prevalence of jhum cultivation, hilly terrain, unpredictable climate changes, low levels of modern input use, poor infrastructure etc. (Karmakar, 2008; Barah, 2006). This cultivation in some form or other is still in vogue as a whole in NERI and is being extensively practiced by more than 100 tribal ethnic minorities (Singh *et al.,* 1996; Ramakrishnan, 1993). The selection of land is made in the months of December and January by the village elders or clan leaders.

In some tribes, community as a whole is collectively responsible for the clearing of the selected piece of land while in others the cutting of trees and shrubs is made by the respective family to whom the land has been allotted. At the time of allotment of land the size and workforce in the family are taken into consideration. The Jhumias adopt mixed cropping. The mixture of crops varies from tribe to tribe within a region. About 35 crops are cultivated in a jhum cultivation system (Arunachalam *et al.,* 2002). The jhum cultivators grow food grains, vegetables and also cash crops. In the mixed cropping, soil exhausting crops, e.g., rice, maize, millets, cotton, etc., and soil enriching crops, e.g., legumes, are grown together. In fact, the grower aims at growing in his jhum land everything that he needs for his family consumption. In other words, the choice of crop is consumption oriented (Priyadarshni, 1996).

With the phenomenal increase in human population the jhum cycle has been increased from 20 to 30 years in the past to about 5 years and in many areas even up to 3 years (Toky and Ramakrishnan, 1981; Singh *et al.,* 1996). The system involves cultivation of crops in steep slopes (Borthakur, 1992). Nearly 57.1% of total geographical area (TGA) in India is under the threat of land degradation mainly by water erosion. On an average, 37.1% of TGA in NE India is in degraded state. Due to short fallow cycles in north-east India resulted in arrested succession, since weedy species were not succeeded by pioneer woody species, and over time the soil seed bank was replaced with seeds of weedy shrubs. Fallows as old as 10 years in the region were dominated by bamboo cover (Raman *et al.,* 1998). However, early colonizers such as bamboo, with relatively faster growth rates in comparison with woody tree species, may have facilitated soil-nutrient recovery and provided microhabitats for regeneration of shade-loving species. The net change in soil available nutrient pool from pre-cropped stage through slashing and burning and subsequent cropping result in substantial lowering of carbon, nitrogen and magnesium (Das *et al.,* 2012).

The continuance of jhum in the north-east states is closely linked to ecological, socio-economic, and cultural and land tenure systems of tribal communities. Since the community owns the lands, the village council or elders divide the jhum land among families for their subsistence on a rotational basis (Rao and Ramakrishnan, 1989). On an average, 3,869 km^2 area is put under jhum cultivation every year. Jhum cultivation in its more traditional and cultural integrated form is an ecological and economically viable system of agriculture as long as population densities are low and jhum cycles are long enough to maintain soil fertility (Tawnenga *et al.,* 1996).

Slash-and-burn land clearing on sloping land may lead to increased soil run-off following disappearance of the protective vegetative cover. In turn, soil run-off and redeposit ion affects soil fertility and spatial patterns of fertility parameters in a field. Soil erosion is an irreversible phenomenon causing land degradation and deterioration of surface water quality. Soil degradation is responsible for making 0.3-0.8% of the world's arable land unsuitable for agricultural production every year and an additional 200 million ha of cropped area would be required over the next 30 years to feed the increasing population (Biggelaar *et al.,* 2004; Lafond *et al.,* 2006).

The jhum cultivation adversely affects eco-restoration and ecological process of forests and this leads to degradation of land causing soil erosion and finally converting forests into wastelands (Dwivedi, 2001). This cultivation practices cause tremendous loss of soil nutrients (Shahlace *et al.,* 1991) and degradation of natural vegetation (Nair and Fernandes, 1984) whereas, this loss can be minimized to almost negligible level by managing the watersheds (Sahoo *et al.,* 1993). The intensity of jhum cultivation practices leads to low rainfall due to destruction of habitat reduces biological diversity and extinction of previously undiscovered indigenous species too. Jhum cultivation causes large-scale damage to the forests and has resulted in deforestation and denudation of hill slopes, exposure of rocks due to soil erosion, heavy silt loading on riverbeds and drying of perennial water resources (Goswami, 1968). Short Jhum cycle makes the land unsuitable for agriculture and leads to considerable loss of soil nutrients through run-off and leaching (Borthakur *et al.,* 1979).

Land degradation in the region is 36.64% of the total geographical area, which is almost double than the national average of 20.17% (Anon. 2000). Burning of above-ground vegetation showed an increase in pH and cations and a decrease in carbon and nitrogen contents in the surface soil (Ram and Ramakrishnan, 1988). Quick release of nutrients especially cations after burning has been reported by Kellman *et al.,* (1985). Fire is often responsible for large nutrient losses due to particulate movement off the field and volatilization during the fire However, there is a clear need for strengthening and improvement in other cases. Strengthening rather than replacement of jhum cultivation is recommendable, especially considering the benefits jhum cultivation has to offer (Yadav, 2013).

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Jhum cultivation practices deteriorate the soil fertility due to huge soil loss of about 2200 t ha^{-1} yr^{-1} (Singh and Singh, 1978). A minimum period of 10 to 15 years is very much essential to maintain the soil fertility for sustainable crop production (Singh *et al.,* 2003). Carbon and Nitrogen in the soil may be among the most limiting factors for plant growth after a forest is cut and then burned. Mishra *et al.,* (2003) reported that only fallow periods under jhum cultivation is not enough for consideration of the restoration capacity of soil. The proper ratio of cropping and fallow should be considered for sustainable Jhum cultivation.

Although, this practice is criticized due to low productivity and environmental diseconomies; continuance of jhum cultivation is closely linked to ecological, socio-economic, cultural identity and land tenure systems of tribal communities there (Deka and Sarmah, 2010). The land-to-person ratio for the NE region (0.68 ha person^{-1}) is much higher than the national average (0.32 ha person^{-1}) (Anonymous 2011a). Although, NERI continues to be a net importer of food grains as despite covering 8.8% of the country's total geographical area, it produces only 1.5% of the country's total food grains production. Further, it was also noted that there was gradually decrease in net land per family in jhum cultivation and increase in permanent agriculture land per family from 1.10 to 0.7 and 0.35 to 0.74 ha family^{-1} respectively (Anonymous 2009). Despite diversification of their economic activities, Jhumias earn meager income from jhum cultivation. Over last decade, the crop productivity has been declined to 50% even after using fertilizers and pesticides to some extent due to land and forest degradation (Mantel *et al.,* 2006). Yields are almost equal to input values and farmers are facing food shortage of 2 to 6 months every year (Rezaul Karim and Mansor, 2011).

Application of fertilizers and plant protection chemicals has been reported negligible in jhum cultivation and their use is also very limited in NERI (Dewangan *et al.,* 2004). In NERI, economy is primarily agricultural which contributes about 30% to gross domestic product. At least 100 different indigenous tribes and over 620,000 families with their own languages and cultural characteristics inhabit here. They mainly depend on Jhum cultivation for their subsistence (Ramakrishnan, 1992). In fact, Jhum cultivation is an ideal solution for agriculture in humid tropics, as long as the human population density is low and fallow periods are long enough to restore soil fertility (Watters, 1971).

Main indicators of poor agricultural growth in NERI include prevalence of traditional agricultural practices, low level of mechanization, small size of operational holdings, high vulnerability to natural calamities and degradation of prime agricultural land and poor irrigation (Barah, 2006). Geophysical conditions limit horizontal expansion of cultivable land (Shaheen *et al.,* 2009; Barah, 2006). As a result, the region is not able to produce adequate food grain to feed its own population (Mishra and Misra, 2006). Under these circumstances, innovative strategy for improving input usage is indeed an indispensable condition for increasing agricultural production with safety and wellbeing of farmers.

Several rehabilitation schemes have been implemented by the state and central governments to control jhum cultivation such as Watershed Development Projects, Soil conservation schemes, Jhum Control Projects, New Land Use Policy Scheme etc. (Tripathi and Barik, 2003). Farmers have a number of constraints, problems or obstacles to switching over from jhum to settled agriculture such as lack of adequate capital for investment, lack of irrigational facilities and non-suitability of land for settlement (Patnaik, 2008). Traditionally, only a small amount of attention has been given to the operator's capabilities and limitations in the design of agricultural hand tools and equipment in northeast India due to lack of proper anthropometric and strength data bases of local people (Dewangan *et al.,* 2010; Agrawal *et al.,* 2010).

1.7 JHUM CULTIVATION IN MIZORAM

Jhum cultivation is the most important and predominant mode of raising food for forest farmers in Mizoram, north-eastern India. As much as 2 lakh hectare land is affected by jhum, with approximately 63,000 ha being cultivated in a given year by 50,000 families (Anonymous, 1987). The average jhum land per family is about 1.3 ha and the present jhum cycle is four years (Anonymous, 1987). According to the report of the Department of Rural Development in Mizoram, 80% of the population resides in the recognized villages. Hence, forest constitute the most important resource of the state, which covers 18,338 Sq. Km representing 86.99% out of total geographical area of 21081 Sq. Km. Forest resources include agriculture land, housing materials, firewood, medicine and food products (Anonymous, 2006). Cropping on jhum lands in Mizoram is predominantly practiced for one year. The second year cropping is scarce, and whenever done, is only on old jhum fallows. Even in other parts of north-eastern India, the land is oft abandoned after first year of cropping, and second year cropping is sometimes practiced with plantations of banana and pineapple (Kushwaha and Ramakrishnan 1987).

However, farmers' apprehension that the yields obtained from the second year of cropping are far lesser than those obtained from cropping new areas, is not tested scientifically. While arguing about reduction in yield during second year cropping the farmers do not take into account the energy invested in slashing and burning newer areas every year, since energy in form of human labour is free for them. The natural vegetation of Mizoram is a typical of "East-Himalayan subtropical wet hill forests" at high altitude and "tropical wet evergreen forests" at low altitude. About 75% of total geographical area is under forest cover (Champion and Seth, 1968).

Ecosystem productivity though increased consequent to fertilizer application both in young and old fields, the per cent increase in young field was almost twice that of old field. This result indicates that the young field exhibits greater fertilizer use efficiency. Tilling is not much useful for improving either ecosystem productivity or economic yield. Inorganic and organic manuring in isolation and in combination respond differently; while inorganic manuring has greater impact on ecosystem productivity, a combination of inorganic and organic manuring is more suitable to improve economic yield during second year cropping (Tawnenga *et al.,* 1996).

The farmers continue the practices of jhum cultivation on the current sites for a few years and then agricultural fields are abandoned. They shift their agricultural fields to the other forest area. After few years gap, they again come back to the previous fields. Mizoram is economically backward region. Its economy is mainly dependent on the traditionally cultivating cereal crops. About 80% people are engaged in agricultural practices. Rice is the main food-grain. The total consumption of rice in Mizoram is 1,80,000 MT whereas, it produces only 44,950 MT rice (25%) (Sati and Rinawma, 2014).

Mizoram is an extremely rugged mountainous region richly endowed with forest resources. The economy of the state is primarily agriculture with majority of the population (52%) practicing jhum (Shifting cultivation). In the past, the main crops were rice, maize, millets and other cereals. Lately, there has been a significant shift, with cereal crops being replaced by vegetables cash crops.

The 1990 Progress Report of Forestry in Mizoram stated that with the increase in population and the need for bringing in more and greater areas under jhum cultivation and urbanization for development, extensive areas have been deforested with the result that forests are now confined mainly to reserve forests and patches of areas not fit for agriculture (Anon., 1990). To replace jhumming, the government introduced a number of policies such as horticulture, terracing and small scale industries and New Land Use Policies (NLUP) between 1990 and 1996, the government spent over Rs. 132 crores to 41,000 beneficiaries (Anonymous, 1996a). Despite these efforts, the practice of jhum agriculture remained more or less the same. Unlike the previous discourse, a new discourse on jhum was brought which discussed how commercial tree plantations, fuel wood, and logging for timber extraction can also have negative impacts on forest (Singh, 1996). Furthermore, alternative systems introduced by the government are not always accepted by the local people (Singh, 1996).

The practice of jhum has an in-built mechanism of sustenance and conservation. However, due to anthropogenic pressure, demand of more food have cleared greater chunks of forests, fallow phase between two successive cropping phases has come down to even 2 to 3 years (Xu *et al.,* 2009). This is adversely affecting eco-restoration and ecological process of forests (Kiyoshi, 1999). Shorter fallow periods are often allowing dominance of herbaceous weeds and soil erosion. As a result, yields are being adversely affected and gradually declining over a period of time.

Among many factors responsible for lower crop yield here, few are prevalence of jhum cultivation, hilly terrain, unpredictable climate changes, low levels of modern input use, poor infrastructure etc. Moreover, anthropological, socio-cultural and economical characteristics of local farmers are also of hindrance for blind adoption of tools/technology copied or transplanted from other geographical region. With this background, in present review an attempt has been made to highlight socio-economic changes due to transition from traditional to settled cultivation in NERI and finds out root causes of low agricultural productivity of this region. Effort has also been made to demonstrate existing scenario of ergonomic interventions in agriculture of NERI and to draw future directions to come up with better ergonomic design strategies for improvement of agricultural hand-tools and machines for making NERI as self-dependent food grain producer (Patel *et al.,* 2013).

Pace of mechanization in NERI has seen a relatively slow progress over the years due to hilly topography, socio-economic conditions, small land holding, lack of farm machinery manufacturing industries etc. Failure for adoption of technology may be due to fragmental land, as 80% farmers belong to small and marginal category (Deb and Ray 2006). Jhum cultivation is characterized as "cafeteria system of cultivation", where almost all the varieties of cereals and vegetables, together with tree crops, are grown in a single field. Development of agriculture and production of food grains in NERI is highly depending upon the custom, culture and food habit of the tribal people (Patel *et al.,* 2013).

In Mizoram, majority of population (~60%) are dependent on agriculture production for their livelihood, however, only 5% of the total area is under cultivation and about 7% of the total cultivated area is under irrigation (Anon., 2010).

Maize and paddy are the major food crops cultivated on the hill slopes and rely on the natural rainfall which is triggered by the south-west monsoon. In addition, pulses, sugarcanes, chillies, ginger, tobacco, vegetables, turmeric, potato, bananas and pineapples are the crops grown in the state. Forest accounts for nearly 89% of the total land area. State has undulating terrain which is divided into hills and valleys. Hills run north to south direction parallel to each other with valleys in between the two hills. Hills can be broadly categorized as: (i) high hills (> 1300 m amsl), (ii) medium hills (between 500 m and 1300 m amsl) and (iii) low hills (< 500 m amsl). According to land classification of the state based on soil survey, 58,638 ha of land has been demarcated as available potential land for paddy and other seasonal crops cultivation. The moderate slopes falling under Class III (55,196 ha), Class IV (1,50,015 ha) and Class VI (10,12,114 ha) which are suitable for terracing, horticulture and plantation crops respectively. (Lalnunmawia and Tripathi, 2015).

At least 70% of the state's total planimetric land area (~2,108700 ha) is sloped at angles steeper than 33 (Anonymous 2009c). Approximately half of all households in Mizoram are engaged in jhum cultivation (Anonymous 2009c), primarily in relatively undeveloped remote villages (Singh *et al.,* 2010). Remote-sensing based estimates of the total area burned each year by farmers and wildfires range from 40,000 to 110,000 ha (Anonymous 2009b&c; Singh and Savant, 2000; Tawnenga *et al.,* 1996). The problems of declining soil fertility, lowered crop productivity, and increased soil erosional losses with shortened fallow periods may be even greater than on gently sloped regions (Fujisaka 1991; Roder *et al.,* 1997; Turkelboom *et al.,* 2008).

The stability and future of many soils is under threat from a wide variety of human activities including over-grazing, poor agricultural practices, land-use change and forest clearance (Chris Park, 2001). Jhum cycles have been drastically narrowed down and due to the loss of soil nutrients, productivity of crop yield decreases (Sharma, 1984). With the increase land use, the cycle of cultivation is affected and it has been observed that, Jhum cycle has been reduced from 10-15 years now to 8-10 years. In some ranges in the district it has come down to 2-5 years. Due to the reduction in cycle, the resilience of ecosystems has been broken down and the land falls into deteriorating condition. Under this, the land is deteriorated with more vulnerable to soil erosion and loss of soil fertility.

1.8 GENERAL DESCRIPTION OF MAIZE

Maize (*Zea mays* L) is the world's most widely grown cereal and it is ranked third among major cereal crops following Rice and Wheat (Ayisi & Poswall, 1997). It is cultivated as a single crop or in mixed cropping. It is a versatile crop and is grown extensively with equal success in temperate, sub-tropical and tropical regions of the world. Maize crop is a key source of food and livelihood for millions of people in many countries of the world (FAO, 2002).

Maize is an annual short days, tall, determinate, C_4 plant varying in height from 1 to 4m producing large, narrow, opposing leaves, borne alternately along the length of a solid stem. Maize plant have an erect stem which bear alternate leaves tassel at the top and auxiliary female inflorescence known as ear in the middle (Azam *et al.,* 2007). All maize varieties follow same general pattern of development, although specific time and interval between stages and total number of leaves developed may vary between different hybrids, seasons, time of planting and location.

Maize is a monoecious plant. It has determinate growth habit and the shoot terminates into the inflorescences bearing staminate (tassel) or pistillate (ear) flowers (Dhillon and Prasanna, 2001). Maize is generally protandrous, that is, the male flower matures earlier than the female flower. Within each male flower spikelet, there are usually two functional florets. Each floret contains a pair of thin scales i.e. lemma and palea, three anthers, two lodicules and rudimentary pistil. Pollen grains per anther have been reported to range from 2000 to 7500. The pollen grains are very small, barely visible to the naked eye, light in weight, and easily carried by wind. The wind borne nature of the pollen and protandry lead to cross-pollination, but there may be about 5 per cent self-pollination (Kiesselbach, 1949).

The female inflorescence or ear develops from one or more lateral branches (shanks) usually borne about half-way up the main stalk from auxillary shoot buds.. As the internodes of the shanks are condensed, the ear remains permanently enclosed in a mantle of many husk leaves. Thus the plant is unable to disperse its seeds in the manner of a wild plant and instead it depends upon human intervention for seed shelling and propagation (Kiesselbach, 1949).

1.8.1 Taxonomy of maize

Maize (*Zea mays* L.) belongs to the family Poaceae (Gramineae) and the tribe Maydeae. The genus *Zea* consists of four species of which *Zea mays* L. is economically important. The other *Zea* sp., referred to as teosintes, are largely wild grasses native to Mexico and Central America (Doeblay, 1990). The number of chromosomes in Zea mays is 2 n = 20.

Tribe Maydeae comprises seven genera which are recognized, namely Old and New World groups. Old World comprises Coix (2n = 10/20), Chionachne (2n = 20), Sclerachne (2n = 20), *Trilobachne* (2n = 20) and *Polytoca* (2n = 20), and New World group has *Zea* and *Tripsacum*. It is generally agreed that maize phylogeny was largely determined by the American genera *Zea* and *Tripsacum*, however it is accepted that the genus Coix contributed to the phylogenetic development of the species *Zea mays* (Radu *et al.,* 1997).

Systematic Position:

Kingdom ----- Plantae

Division ----- Magnoliophyta

Class ----- Liliopsida

Order ----- Poales

Family ----- Poaceae

Genus ----- *Zea*

Species ----- *Z. mays*

1.8.2 History of maize cultivation

The center of origin for *Zea mays* has been established as the Mesoamerican region, now Mexico and Central America. Archaeological records suggest that domestication of maize began at least 6000 years ago, occurring independently in regions of the southwestern United States, Mexico, and Central

America (Watson and Dallwitz, 1992). The Portuguese introduced maize to Southeast-Asia from the America in the 16th century. The maize was introduced into Spain after the return of Columbus from America and from Spain it went to France, Italy and Turkey. In India, Portuguese introduced maize during the seventeenth century. From India it went to China and later it was introduced in Philippines and the East Indies. Maize now is being grown in USA, China, Brazil, Argentina, Mexico, South Africa, Rumania, Yugoslavia and India. In respect of production USA stands first (Mangelsdorf, 1974).

Various hypothesis have been proposed on the origin/domestication of maize (OECD, 2006). Teosintes (*Z. diploperennis* and *Z. mays* sp. mexicana) and Tripsacum species are often described as having roles in the domestication process of maize (Mangelsdorf, 1974; Galinat, 1988). An early hypothesis proposed that *Z. mays* sp. mexicana was the product of a natural hybridization of Tripsacum and Zea (Mangelsdorf, 1974). Further crossings of teosinte with wild maize are thought to have produced the modern races of maize. The possibility of intergeneric hybridization of either Z. diploperennis or Tripsacum with an extinct wild maize has also been proposed as the ancestral origin of Z. mays (Radu *et al.,* 1997; Purseglove, 1972). Eubanks (1993, 1997a) suggests that domesticated maize may have arisen via human selection of natural hybrids between Tripsacum and perennial teosinte.

1.8.3 Germplasm diversity

Maize is a cultivated crop throughout the world and accordingly germplasm resources are preserved ex situ in many parts of the world. Most of the maize variation can be found in the Meso-American region and the northern part of South America. The great diversity of environments and conditions have created the basis for the development of maize varieties well adapted to harsh conditions of soil and climate as well as to biotic stresses. There is a close correlation among community culture, production system and the type of consumption of maize, with the diversification and variation of maize (Aguirre *et al.,* 1998; Louette and Smale, 1998). There is a growing trend in developing countries to adopt improved maize varieties. In Mexico, only 20% of the corn varieties grown 50 years ago remain in cultivation (World Watch Institute, 2000). CIMMYT (International Maize and Wheat Improvement Centre) has taken the lead in preserving maize germplasm. It has the world's largest collection of maize accessions, with over 17,000 lines (CIMMYT, 2000).

India also harbours diverse maize germplasm (Singh, 1977; Wilkes, 1981). An extensive collection of germplasm from the entire NEH region has been made by the Indian Agricultural Research Institute, New Delhi. It has been shown that the two primitive Sikkim maize strains (Sikkim Primitive 1 and Sikkim Primitive 2) were different from the primitive Mexican races (Mukherjee *et al.,* 1971). Indian maize races have been classified under four categories i.e. primitive group, advanced or derived group, recent introduction and hybrid races (Singh, 1977). The National Gene Bank at New Delhi houses about 6,000 indigenous accessions primarily from the NEH region. Systematic and comprehensive evaluation of this germplasm is being attempted for agronomically useful traits (Prasanna et al, 2009). In addition to the races, there are several local varieties in India. The genetic variability has resulted by crossing of Indian germplasm with strains imported from other countries particularly USA (Mukherjee, 1989). It has been reported that crosses of Indian x Indian germplasm gave yield superiority of 24-43 per cent, whereas Indian x US dent germplasm out yielded local varieties by 58 per cent (Dhawan and Singh, 1961).

Highest yielding single cross hybrids were obtained from crosses between Indian x USA germplasm followed by USA x USA and Indian x Indian germplasm, thus highlighting the significance of genetic divergence for obtaining higher yields (Ahloowalia and Dhawan, 1963). Dent x flint crosses involving Indian and Caribbean, and Indian and US germplasm showed highest expression of heterosis over better parent (47-54%) (Mukherjee and Dhawan, 1970).

1.8.4 Conditions for maize cultivation

Maize crop is primarily a warm weather crop and it is grown in wide range of climatic conditions and it is more extensively distributed over the earth than any other local crops Maize is a *kharif crop* and is grown as a summer annual. Maize cultivation consists of sowing, harvesting, threshing (ICAR, 2006). It is widely cultivated from the sea level up to altitudes of 2,500m. Maize grow best under Sub-tropical condition. The temperature requirements of the growing plant ranges from 21^0C to 28^0C. The plant requires about 140 days of bright warm sunshine and about 60-120cm of average rainfall, to attain full maturity. An alkaline, well-drained loamy soil produces the best results. It can’t withstand frost at any stages of its growth (Onwueme and Sinha, 1991).

Maize require fertile, deep and well-drained soil. However, it can be grown on any type of soil, ranging from deep heavy clays to light sandy ones. It is necessary that, the pH of the soil does not deviated from the range of 7.5 to 8.5. Maize crop requires about 50% of its total water requirement in a short period of 30-35 days after tasselling. The productivity of maize largely depends on its nutrient requirement and management particularly that of nitrogen, phosphorus and potassium (Arun *et al.,* 2007).

Maize has a high grain yield potential, which is determined by the genetics of the cultivated hybrid and is influenced by the environmental factors that are affecting the plant growth. In order to fully explore their capacity to transform solar radiation into grain production, it is necessary to understand how plants interact morphologically and physiologically in a community and to identify the management practices which allow them to maximize the use of growth resources (Sangoi, 2001).

Maize yields variations between regions or agro-ecological zones can be attributed to various factors of which some are agronomic like plant density, planting dates, and soil fertility (Banziger *et al.,* 2000). Successful maize production requires an understanding of various management practices as well as environmental conditions that affect crop performance (Eckert, 1995).

1.8.5 Economic importance of maize

Maize is an important food crop grown commercially in large scale and at subsistence level by many resource poor farmers. It is known as queen of cereals because it has the highest genetic yield potential among the cereals. It matures earlier than most food crops and it is used in homes to prepare different dishes especially during the “hungry period” of June - July when most other crops had been planted by the farmers (Onwueme and Sinha, 1991).

` Maize has great significance as human food, animal feed and raw material. In most developing countries, about 50 to 55 percent of the total maize production is consumed as food. Maize has high production potential especially under irrigated condition when compared to any other cereal crop. The maize grain can be prepared for food in many different ways (fried, grilled, in a salad or soup). Processing maize can also produce a wide range of products such as corn flour and corn meal. Maize is also used in livestock feed (poultry, pigs, cattle) in the form of grains, feed milling or as fodder (Morris, 1998).

The use of maize varies in different countries. In USA, European countries, Canada and other developed countries, maize is used mainly to feed animals directly or sold to feed industry and as raw materials for industrial products such as starch, glucose, dextrose (FAO, 1999), starch and specialized foods. Starch in turn involves in the enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint. It is also being recently used as biofuel (Galinat, 1988; Shaw, 1988, Mexico, 1994). Most people regard maize as a breakfast cereal. In Latin America and Africa the main use of maize is for food while in Asia it is used for food and animal feed. In fact in many countries it is the basic staple food and an important ingredient in the diets of people. Globally, it has been estimated that approximately 21% of the total grain produced is consumed as food (Shaw, 1988).

In India, about 28% of maize produced is used for food purpose, about 11% as livestock feed, 48% as poultry feed, 12% in wet milling industry (for example starch and oil production) and 1% as seed (AICRP on Maize, 2007). The increase in consumption of maize is also due to the renewed interest in traditional dishes and diversified maize production, that can be used for livestock feed or industrial energy, because it is adapted to a wide range of environmental conditions (Malvar *et al.,* 2008). Maize is a crop par excellence for food, feed and industrial utilization. (Gopalan *et al.,* 2007).

Table 1.1: Composition per 100 g of edible portion of maize (dry)

Moisture	14.9 g	Minerals	1.5 g
Protein	11.1g	Carbohydrates	66.2 g
Fat	3.6 g	Calcium	10 mg
Fibre	2.7 g	Iron	2.3 mg
Calories	342	Potassium	286 mg
Phosphorus	348 mg	Thiamine	0.42 mg
Sodium	15.9 mg	Carotene	90 ug
Sulphur	114 mg	Vitamin C	0.12 mg
Riboflavin	0.10 mg	Magnesium	139 mg
Amino acids	1.78 mg	Copper	0.14 mg

However, it is deficit in essential amino acid, lysine and tryptophan. To overcome this deficiency, quality protein maize (QPM) with sufficiently higher quantity of lysine and tryptophan have been developed.

1.8.6 Maize production

Maize is cultivated on nearly 178 million ha globally in about 160 countries and contributes ~50% (1,170 million MT) to the global grain production. The major maize production areas are located in temperate regions of the globe. The

United States, China, Brazil and Mexico account for 70% of global production. India has 5% of corn acreage and contributes 2% of world production (FAOSTAT, 2014).

Table 1.2. Top ten maize producers in 2013 (FAOSTAT 2014)

Country	Production (tonnes)
United States	353,699,441
China	217,730,000
Brazil	80,516,571
Argentina	32,119,211
Ukraine	30,949,550
India	23,290,000
Mexico	22,663,953
Indonesia	18,511,853
France	15,053,100
South Africa	12,365,000
World	1,016,431,783

Animal feed is the largest end use segment for maize in Asia with ~70% of total volumes used by feed industry. It is estimated that the demand for maize will be fueled by population growth and increasing inclination towards higher protein consumption in the form of meat and eggs. Maize, as poultry feed, is more acceptable than rice and wheat both in terms of price and nutrition. The nutritional value of maize is higher (3,365 Kcal/kg) compared to rice (3,320 Kcal/kg), rice bran

(2,620 Kcal/kg), peanut (2,915 Kcal/kg) and oilcake (2,350Kcal/kg). Apart from feed and industrial applications, food processing industry is a crucial end use segment for maize as it is being used for making food additives and sweeteners. With processed food industry slated to grow at 10%+ rate in the next five years in most countries of South East Asia maize demand is expected to rise. As per the OECD agricultural outlook report, biofuel volumes for southeast Asia are expected to grow from 4.9 billion liters in 2013 to 7.5 billion liters by 2021 at an annual growth rate of 5.5% backed by favorable policies in SE Asian countries (FAOSTAT 2014).

In India, maize constitutes about 9% of the total volume of cereals produced and is the third most important food grain after rice (~42%) and wheat (~38%). Advance estimates for total production in India stands at 9.3 million MT in trade year 2015, growing at about 6% in the past 5 years (Farnharm *et al.,* 2003). Maize has diverse industrial applications with its primary usage being in feed. Poultry industry is heavily dependent on maize as it forms 50-60% of the input required for broiler feed and 25-35% of the input required for layer feed. Broilers consume 3.6-4 kgs of feed over a period of 32 - 35 days (5 weeks) to attain weight of ~2.2 kg. Layers have a life span of ~72 weeks of which they lay eggs for 52 weeks with an annual feed consumption of 42 - 47 kgs, producing over 300 eggs. The industry standard for energy requirement is 3,200 Kcal/ kg in case of broiler feed and 2,300 Kcal/ kg in case of layer feed. Maize provides approximately 3,400 kcal/ kg and is most preferred due to availability and higher energy content. Jowar is the closest substitute but its availability is constrained while wheat contains high non-starch polysaccharides which are indigestible by broilers and have to be depolymerized with an enzyme for release of energy. Better quality maize can be developed for this industry with higher energy content in order to ensure there is no substitution (ICAR, 2006).

1.8.7 Maize cultivation and production in Mizoram

In Mizoram more than 90 percent of the area comes under hills (Vishwakarma *et al.,* 2012). Agriculture occupies a very important place in the economy of Mizoram. As per Economic Classification of workers 2001 census, about 60% percent of the total workers are engaged in Agricultural and allied sector. The economic life of the Mizo has always been centered around jhum or shifting cultivation (Economic Survey Mizoram 2013-14).

Maize is the second most important crops next to paddy in jhum areas and is generally sown with the onset of monsoon as kharif crop. However, increasing trends in production for Rabi maize is also observed with the introduction of new high yielding varieties associated with irrigation facilities. In term of area and production in Mizoram, maize occupy 10810 ha (Kharif) and 932 ha (rabi) respectively. (Anonymous, 2007). The other common crops in Mizoram are cucumber, beans, ginger, mustard, sesame, cotton etc. It is also practiced by the Mizo farmers to grow multiple crops together with maize. Some of the most common crops mixed with maize are brinjal, chilli, sesame, mustard, peas, pumpkin and white pumpkin. In Mizoram, Maize is graded in two varieties viz. big maize (Locally named Mimpui) and sticky maize (Locally named Mimban).

The total area under maize cultivation is also increased from 8000 ha. during 2012-13 against 6905 ha during 2011-12 which account for 15.85 % increased in area and 25.04 % increased in production over the preceding years (Economic

Survey Mizoram 2013-14). Maize is not only important for humans but also being consumed as feed materials for poultry and pigs. The productivity of maize is low (1621 kg/ha) as compared to the national productivity of 2000 kg/ ha (Vishwakarma *et al.,* 2012).

In the early period of agriculture in Mizoram, sufficient land was available to meet the demand for agricultural land of the low density population. After cultivation, the land was left fallow for about 25 years or even more which synchronized well with the time required for the maturity of the forest and recovery of the fertility of the soil. However, with the increase in population, the pressure on land has increased and consequently, the fallow periods have been reduced significantly leading to the transformation of once a fertile land into unsustainable marginal land (Tawnenga *et al.,* 1996).

Maize cultivation in the jhum and valley with little or without chemical and organic fertilizers is a limiting factor of increasing productivity in Mizoram. The farmers used locally available low cost manure as sole nutrition to the rainfed maize crop grown mainly in jhum, valley or home yard land. Moreover, due to the introduction of "The Mizoram organic Bill 2004" on 12th July 2004, organic farming plays a very significant role as far as production of crops is concerned for the whole state of Mizoram (Economic Survey Mizoram, 2013-14). Farmers are therefore encourage to adopt the utilization and package of practices of various green manuring crops and bio-fertilizers so as to boast the production and also to improve the soil fertility status in the long run the best time of growing, and number of population in an area by providing them research base data and figures.

1.9 Scope of the study

Despite of the long history of maize cultivation, standardization and optimization of its production with reference to cultural practice is lacking in Mizoram. The total production of maize is not sufficient to meet the requirement of maize for the population of Mizoram (Anon., 2006). The cultivation of maize with proper management of soil fertility status by application of different doses of NPK fertilizers and plant population/spacing on an input requirement may be the only possible solution to increase the productivity of maize in Mizoram on sustainable basis. Besides there is an increasing population in the state due to which jhum cultivation with short duration cycles is now being considered as an economic as well as environment liability.

However, research findings on maize cultivation, its nutritional requirements and the influence of fertilizers and plant spacing on growth and yield attributes of the local maize variety (Mimpui) are very scarce. The present study therefore, aims to investigate the growth and productivity of maize with different fertilizer doses and different plant population density in different fallow periods of Mizoram. It is expected that the present study would help in suggesting the most suitable plant spacing and appropriate soil and nutrient management to increase the productivity of maize in different jhum cycles.

1.10 Objectives

The present study aims to understand the comparative analysis of growth and productivity of maize in different jhum cycles of Mizoram. Thus, the specific objectives of the present study are as follows:

1. To study the effect of different fertility levels on growth and yield of maize under different jhum cycles.
2. To find out the suitable spacing for growth and yield of maize.

Chapter – II

REVIEW OF LITERATURE

2.1 Jhum cycles and sustainable agriculture

The length of the cultivation period varies depending on the region (one to three years), but is always shorter than the fallow period. The fallow period may be natural or managed and allows recovery from the soil degradation resulting from conversion and cultivation. The duration of the fallow period is variable, but it must be long enough for woody vegetation to become dominant (Eden and Andrade, 1987; Kleinman *et al.,* 1995; Mertz *et al.,* 2009). The jhum cultivation leads to the formation of mosaics of secondary forests in different stages of regeneration, contained within a mature forest matrix that helps to sustain them (Conklin, 1961; Harris, 1971; Hiraoka and Yamamoto, 1980; Egger, 1981; Altieri *et al.,* 1987; McGrath, 1987; Adams, 2000a; Martins, 2005).

Jhum cultivation appears to be sustainable under specific conditions of low demographic densities and the use of low input technologies (Kleinman *et al.,* 1995; Johnson *et al.,* 2001; Pedroso junior, 2008, 2009). However, the rapid and important climatic and economic-political transformations that have occurred in recent decades (Mertz, 2002; Pedroso-Junior *et al.,* 2008, 2009; Van Vliet *et al.,* 2012) have produced a growing concern about the sustainability of SCS (Bruun *et al.,* 2009) and the food security of subsistence farmers (Altieri *et al.,* 1987; Adams *et al.,* 2005).

During the 1950s, the Food and Agriculture Organization of the United Nations (FAO, 1957) requested that governments, research centers, and public and private associations invested in the modernization of agricultural practices and disregarded those associated with shifting cultivation. According to FAO, shifting cultivation represented a backward and inadequate system for the conservation of the tropical forest ecosystems in which it was practiced (Mertz *et al.,* 2009). The practice of Jhum is not, merely exercised by the tribals for their sustenance, but a traditional method of earning a livelihood, a traditional farming system that uses local product and techniques, has rooted in the past, has evolved to their present stage as a result of the interaction of the cultural and environmental condition of the region and is deeply embedded in the tribal psyche (Gupta, 2005).

Chhauchhuak (2004) reported that crop mix of perennial and season crops in Jhum cultivation allows phased harvesting ensuring food security throughout the year and also provide needed diversity for nutrition and food preferences. Sarangi & Singh (2007) observed that pseudo cereals, small millets, indigenous pulses, oil seeds and many forest plants form an important component of food source for the tribal population. Species have been used as life sustaining food as well as medicines from time immemorial.

The availability of Non Timber Forest Products serves as an important gap-filler when food stocks are low and also as a source of income. For example, the collection of indigenous fruits contributes between 5.5 and 6.5% to the total household income in the rural communities of Southern Africa (Akinnifesi *et al.,* 2008). The tribal people of the Chittagong Hill Tract of Bangladesh still practice jhum as a principal source of livelihood. But a rapid rise in population (both endemic and migration influx of plains people), the construction of development infrastructure (e.g. hydroelectric projects), and government policies on expansion of reserve and protected forests has made the jhum vulnerable (Nath *et al.,* 2005). Belsky & Siebert (2003) stated that farmers in the Chittagong Hill Tract who live mostly in inaccessible hilly areas and are deprived of all humanitarian services and facilities are forced to practice traditional jhum. In order to maintain their livelihoods, there is need to balance food and income generation, and a combination of on- and off-farm enterprises helps to maintain the balance.

Forest income arises more from non-timber forest products (NTFPs) and forest ecosystems services than from timber. The mere existence of forest resources and related cultural heritages is not enough for local communities to obtain income from forest land. Proper arrangements for local communities in accessing the forest resources and knowledge of making use of the resources is required to make the relationship constructive for people's livelihood in South Korea (Yeo-Chang 2009). Mertz (2002) stated that although introduced changes may indeed be very valuable for local livelihoods and environment, there is little evidence that shifting cultivation will ever reach a stage of environmental degradation and low productivity, which could be considered a "breakdown" of the system.

Toky and Ramakrishnan, (1981) compared the structure and functional aspects of three agro-ecosystem types i.e, jhum cultivation, valley rice cultivation and terrace cultivation and reported that the 30 year jhum cycle has the advantage over the 10 or 5 year cycle apart from higher yields, in that the monetary output/input ratio under a 30 year jhum cycle is comparatively favourable.

Lele *et al.,* (2008) studied six historical data sets of Northeastern region (NER) of India, one of the largest reserves of forests in India, generated from remote sensing data (1972, 1982, 1987, 1989, 1993 and 1999) and are used to assess forest cover loss, shape index and entropy to the degree of forest fragmentation over a multi-decadal period. The assessments have been carried out in the open (40–10% canopy density) and close (>40% canopy density) forest cover classes. The range of shape index and deviation from the actual mean in open forest and closed forest were computed separately. The patches among two categories were further analyzed based on patch area into six classes; ranging from <1 km^2 to >500 km^2. This also indicates variability of the forest patches. It is noteworthy that patches of area within 1–10 km^2 and 10–50 km^2 have been severely fragmented. This loss could be attributed to the shifting cultivation practice where the patches of moderate size are cultivated by group of families.

The practice of jhum is not merely another exercise by the tribals for their subsistence, but a traditional method of earning a livelihood, a traditional farming system that uses local products and techniques, has roots in the past, has evolved to their present stage as a result of the interaction of the cultural and environmental conditions of the region and is deeply embedded in the tribal people (Katherine, 1991).

The influence of fallow period on economic yields and soil biogeochemistry were studied by comparing replicate fields of similar slope that were under 5, 10 and 30 year fallow rotation periods. Mean annual total economic yields over a full rotational cycle were twice as high in the 10 and 30 year compared to the 5 year fallow systems (Toky and Ramakrishnan 1981a). Mean annual losses of major soluble nutrients in run-off (plus downward percolating waters) did not differ between fields of varying fallow period, but surface run-off sediment losses were ~40% higher in the shortest fallow fields (Toky and Ramakrishnan 1981b).

Cultivation on burned sites could be extended by effective cropping in the second year after burning was tested in two sites under differing fallow periods in Mizoram (Tawnenga *et al.,* 1996). Ecosystem productivity (total dry matter production in crops and weeds) in a 6 year fallow site during the two successive years after burning was 45 and 22% lower, respectively, than in a 20 year fallow site. Soil organic carbon, total nitrogen, extractable phosphorus and exchangable cation pools were all depleted in the shorter fallow site, and soluble nutrients progressively declined during each of the successive cropping years at both sites (Tawnenga *et al.,* 1997b). Commercial fertilizer and/or farmyard manure additions in the second year elevated productivity in the short and long fallow period sites by ~50 and ~33%, respectively.

2.2 Effect of Fertilizers on Maize

Integrated use of balanced inorganic fertilizer in combination with lime and organic manure sustains a better soil health for achieving higher crop productivity under intensive cropping systems in hilly ecosystem of north eastern India. Study suggests that addition of NPK fertilizers along with organic manure, lime, and biofertilizers had increased SOC content, aggregate stability, moisture retention capacity, and infiltration rate of the soil while reducing bulk density. The SOC content under the treatment 100% NPK + lime + biofertilizer + FYM was significantly higher (68.6%) than control plots (Saha *et al.,* 2010).

It was reported that the low fertility status of most tropical soils hindered maize production as maize has a strong exhausting effect on the soil. It was generally observed that maize fails to produce good grain in plots without adequate nutrients (Adediran and Banjoko, 2003). Inorganic fertilizer exert strong influence on plant growth, development and yield (Stefano *et al.,* 2004).The availability of sufficient growth nutrients from inorganic fertilizers lead to improved cell activities, enhanced cellk multiplication and enlargement and luxuriant growth (Fashina *et al.,* 2002). Luxuriant growth resulting from fertilizer application leads to larger dry matter production (Obi *et al.,* 2005) owing better utilization of solar radiation and more nutrient (Saeed *et al.,* 2001).

Yield differences between temperate and tropical areas have been attributed to low nutrient status of tropical soils especially nitrogen, phosphorus and potassium resulting from the practice of slash and burn farming system associated with bush fallow and with excessive leaching of the soil nutrients. This system is presently unsustainable due to high population pressure and other human activities which have resulted in reduced fallow period (Steiner, 1991).

Acid soils are highly weathered and contain large quantities of Al and Fe hydrous oxides that have the ability to absorb major elements onto their surfaces such that much of added nutrients are fixed instead of being made available for crop use (Enwezor *et al.,* 1981; Akinrinade *et al.,* 2006). Vast areas of tropical lands that were once fertile have been rendered unproductive due to continuous cultivation and erosion which caused physical degradation, loss of soils organic matter and decreased cation exchange capacity (CEC) and as well as increased Al and Mn toxicity (Mba, 2006). As these soils suffered multi-nutrient deficiencies, application of mineral fertilizers has become mandatory to increase crop yields. However, mineral fertilizers are commonly scarce, costly, having imbalanced nutrition and their use could exacerbate the problem of soil acidity (Oguike *et al.,* 2006; Nottidge *et al.,* 2006).

Nitrogen is a primary nutrient required by crop plants for their growth and development. Nitrogen plays a key role in vegetative growth and grain production of maize plant (Adediran and Banjoko,1995; Shanti *et al.,* 1997). The application of nitrogen not only affects the forage yield of maize, but also improves its quality especially its protein contents (Haque *et al.,* 2001). It is reported that application of nitrogen to maize increase fodder nutritive value by increasing crude protein and by reducing ash and fiber contents (Baran, 1987). Plant height, stem diameter, green fodder yield, protein, fiber, and total ash content were increased by increasing nitrogen levels. It also mediates the utilization of phosphorus, potassium and other elements in plants (Brady, 1984).

Phosphorus is considered an essential nutrient to plant growth and development. It is an integral part of nucleic acid and is essential for cellular respiration and for metabolic activity. Therefore, the use of phosphorus along with nitrogen will help increase yield of maize (Safdar, 1997). Phosphorus application increased fodder yield and quality by increasing plant height, and the number of leaves plant1 (Masood *et al.,* 2011).

Potassium is a multifunctional and high mobility element with direct and in direct influence on almost all biochemical and biophysiological processes. It catalyzes numerous enzyme reactions. It helps the formation, transport and deposit of the products of photosynthesis in fruits, grains, tubercles and contributes to their transformation in fibers proteins, fats and vitamins (Adediran and Banjoko,1995). Potassium increases root growth and improves drought resistance; maintains turgor; reduces water loss and wilting reduces respiration, preventing energy losses; enhance strains location of sugars and starch; produces grain rich in starch, increases protein content of plants, builds cellulose and reduces lodging, helps retard crop diseases. Potassium plays significant roles in enhancing crop quality (Rehm *et al.,*1983).

The nitrate N is easily lost through leaching and denitrification in field soil, whereas the ammonium N is usually lost through volatilization (Janzen *et al.,* 2013; Li *et al.,* 2014). Many approaches have been practiced for improving N utilization efficiency in crops, for example, optimal time, rate, and methods of application for matching N supply with crop demand and the use of specially formulated forms of fertilizer. The results showed that N application by stages can significantly increase maize grain yield compared to disposable application as sowing manure (Yu *et al.,* 2010). Zhang *et al.,* (2014) reported that the regulating N application (240 kg/ha, divide into 3 equal amounts, each about 80 kg, used as base fertilizer, tillering fertilizer, and booting fertilizer) could increase rice yield while substantially reduced N leaching losses and improved N use efficiency.

Nitrogen has a major effect on growth among the major nutrients needed by plants (especially the three elements of N, P, K) (Costa *et al.,* 2002., Kagbe and Aderian, 2003) and Plants give it different responses. Maize need to nitrogen is different due to weather conditions, soil type and maize rotation (Bundy, *et al.,* 1993., Green and Blackmer, 1995).

Soil nutrition absorbed by crops can be divided into mobile and immobile (Barber, 1995). Nitrogen (N) in form of nitrate and water are highly mobile and required in largest amounts by crops. Phosphorus (P) is the most immobile, and potassium (K) is also relatively immobile, both of which are macronutrients required by crops (Marschner, 2012). The contents of N, P and K in agricultural soil are affected by plant growth and yield (Havlin *et al.,* 2004). Therefore, crop yield is limited by two important mobile resources, including nitrate and water, as well as two immobile resources, P and K (Lynch, 2013).

Khan *et al.,* (2014) investigated the response of maize to three phosphorus rates (60, 90 and 120 kg·ha^{-1}) and four nitrogen rates (90, 120, 150, 180 kg·ha^{-1}) for number of plant per m2 (NP m^2), plant height (PH), number of leaves plant^{-1} (NLP), fresh weight of plants kg·ha^{-1} (FW) and dry weight of plant kg·ha^{-1}. Results of the study showed that application of N @ 180 and P @ 120 kg·ha^{-1} significantly increased fodder yield of maize. The linear increase in biomass yield clearly indicated that N was a limiting nutrient factor and that N demand along with P has a positive response. At higher application rates, N fertilizer significantly increased biomass component, improved N uptake with increasing nitrogen use efficiency and decreased its losses to the environment and below plant zone.

A two years field study was conducted to examine the agronomic response, efficiency and profitability of fertilizer microdosing in maize with the rate of 27 + 27, 53 + 53 and 80 + 80 kg ha^{-1}, and banding of fertilizer with 100 + 100 kg ha^{-1} of di ammonium phosphate (DAP) + urea, applied at planting and jointing, respectively. The 27 + 27 kg ha^{-1} fertilizer rate increased the grain yield by 19, 45 and 46% and it was equivalent to the higher rates. The value cost ratio (VCR) was highest with the lowest fertilizer rate, varying between seven and 11 in the treatment with 27 + 27 kg ha^{-1}. The improved yield, Fertilizer Use efficiency (FUE), Value Cost Ratio (VCR) and gross margin in maize with microdosing at the 27 + 27 kg ha^{-1} of DAP + urea rate makes it low cost, low risk, high yielding and profitable. (Sime and Aune, 2014).

Xian *et al.,* (2014) conducted an experiment to study the effects of different N application rates on the yield and nitrogen utilization efficiency of summer maize and reported that the yield increased at first and then decreased with the increase of N application rates. With the increase of N application rate harvest index (HI) and N harvest index (NHI) decreased. The highest HI and NHI was obtained at N application of 189 kg/ha (N189) and 178 kg/ha (N178). Excessive N application rate reduced N recovery efficiency (NRE) and N partial fertilizer productivity (NPFP) by 29%-55% and 32-64 kg/kg compared with N189 and N178, respectively. Agronomic efficiency(AE) and physiological efficiency(PE) increased at first then decreased with the increase N application rate, and the highest AE and PE were appeared at N application rate of 200 kg/ha.

It was reported that the grain yield of maize increases first, and then decreases with the increase of nitrogen application rates, and reaches the highest at 150-180 kg N/ha, appropriate nitrogen rate could improve grain equality, N use efficiency and N partial factor productivity decline as N application increased, respectively. (Hu *et al.,* 2014).

Nitrogen element is the nutrient that most frequently limits yield and plays an important role in quality of forage crops (Jules, 1974). Positive response of nitrogen fertilizers has been reported by Koul, (1997). Nitrogen fertilization increased number of leaves per plant and leaf area (El Noeman *et al.,* 1990 and Gasim, 2001). John and Warren (1967) noted that the addition of nitrogen increased stem diameter. Koul_(1997) recorded that nitrogen application resulted in greater values of plant height, leaf area, number of leaves and stem diameter of fodder maize, fresh and dry forage yield were also increased due to addition of nitrogen. Leaf to stem ratio was found also to be increased by nitrogen (Duncan, 1980).

Gasim (2001) reported that the increase in leaf to stem ratio with nitrogen application is probably due to the increase in number of leaves and leaf area under nitrogen treatments, producing more and heavy leaves. The uptake of nitrogen by maize is low during early development and increased at tasseling. Although only relatively small amounts of fertilizers are required during the very early stages of plant growth, high concentration of nutrients in the roots zone at that time are beneficial in promoting early growth (Ritchie *et al.,* 1993).

Sharma (1973) observed that addition of nitrogen fertilizer increased plant height. Increase in plant height resulted in an increase in leaf number per plant as reported by Akintoye, (1996). Gasim (2001) indicated that the increase in plant height with nitrogen fertilizer is due to the fact that nitrogen promotes plant growth, increases the number of internodes and length of the internodes which results in progressive increase in plant height. Turkhede and Rajendra, (1978) and Koul, (1997) reported similar results. Tripathi *et al.,* (1979) found that application of nitrogen gave a significant additional increase in crude protein contents of forage oats.

Kalifa *et al.,* (1981) studied the effect of nitrogen on an open-pollinated variety of corn which was given as ammonium nitrate applied as nitrogen source. His results indicated that ammonium nitrate fertilizer increased the number of days to mid- tasseling, mid-silking and shelling percentage. Singh *et al.,* (1986) found that the biological yield, content and uptake of nitrogen in grain and stover of maize were highest with nitrogen as urea applied in two split dressings. Nitrogen had significant effects on chemical composition of leaves, plant height, leaves, internodes number per plant at early stages. Nitrogen also significantly affected final seed yield and some yield components such as number and weight of cobs/m^{2}and weight of seeds per cob, also significantly affected straw yield. In addition nitrogen had significant effect on seed protein content and seed and leaf P content (Omara, 1989).

High cost of inorganic fertilizers has precluded their use by smallholder farmers to remedy the problem of soil acidity and infertility. Lime and P-fertilizer significantly affected only the top-soil pH, Ca, Mg and available P, while the effects of N-fertilizer were evident on both top- and sub-soil N likely due to its faster mobility than P and lime (Kisinyo *et al.,* 2015).

Phosphorus is one of the most important nutrients for sustainable crop production in most acid soils of the tropics and subtropics (Ryan, 2002). Phosphorus has a vital role in energy storage, root development and early maturity of crops. The P requirement of crops is very high during initial stages of plant growth (Latif *et al.,* 1992). It has functions of a structural nature in macromolecules such as nucleic acids and of energy transfer in metabolic path- ways of biosynthesis and degradation. Unlike nitrate and sulphate, phosphate is not reduced in plants but remains in its highest oxidized form (Marschner, 1993).

Enujeke (2013) recommended the application of 450kg ha^{-1} of NPK 20: 10:10 or 30 tha^{-1} of poultry manure for increased grain yield of maize. The report further argued that poultry dropping and cattle dung increases root growth of maize and the crop extracts soil water more efficiently for increased grain yield.

The values of N, P and K were higher in poultry manure than in cattle dung because poultry manure, especially those produced in deep litter or battery cage house, have more concentrated nutrient content compared with other types of animal manure. This is similar to the findings of Sharpley and Smith (1995), Lombin *et al.,* (1991). Low soil fertility of tropical soils, particularly low nitrogen, ranks the second most important abiotic constraint to maize production in tropical ecologies (Pingalli, 2001). Intensified land use and the rapid decline in fallow periods, coupled with the extension of agriculture into marginal lands, have contributed to a rapid decline in soil fertility. Nitrogen (N) and phosphorus (P) deficits are a severe and widespread biophysical constraint to smallholder maize productivity, and in turn to the long term food security (Sanchez *et al.,* 1997).

Ekesiobi *et al.,* (2015) reported that the combined application of organic and inorganic fertilizers significantly increased the plant height, number of leaves, stem girth, leaf area and leaf area index and number of cobs, ear length, ear diameter, weight of ear, weight of cob, 100 grain weight, grain yield t/ha and above ground weight (yield parameters), particularly 10 t/ha poultry manure combined with 75 kg/ha urea, followed by 10 t/ha poultry manure. The application of 5 t/ha poultry manure combined with 75 kg/ha urea performed better than 150 kg/ha urea as well as the no fertilized plants. The application of organomineral fertilizers, especially 10 t/ha poultry manure combined with 75kg/ha was recommended for enhanced maize production.

Maize requires heavy fertilizer application for optimum yield in terms of nitrogen derived from chemical or organic fertilizers (Awotundun, 2005). Maize therefore is high demanding crop for nitrogen than any other cereals (Onwueme and Sinha, 1991). However, the amount applied depends mainly on the projected maize yield that appears available and attainable in the locality and the fertility level of the soil as determined by soil test (Shukla, 1990). FPDD, (2002) reported a significant difference in grain yield of maize due to application of fertilizer (ammonium sulphate).

Bationo and Lompo (2003), reported significant increase in yield of maize with application of mineral fertilizer. But yield was higher when mineral fertilizer was combined with organic manure. Phosphorus up take in maize was increased with application of poultry droppings in combination with chemical fertilizer. A tremendous response of maize to foliar application of boron in the presence of FYM was also recorded. Awotundun (2005), found increased height and grain yield of pop-corn with application of FYM and NPK fertilizers when applied in combination. Azeez *et al.,* (2007) also observed good response of maize to application of crop residues in form of burnt ash. But the response was for a short time. For a sustained increase in soil nutrient levels and yield of maize, incorporation of ash should be complemented with mineral fertilizers.

It was reported that maize with combined application of Zn (1.5%) and NPK fertilizer significantly improved plant height, 1000-grain weight, yield, grain yield and harvest index as compared to the treatment fertilized only with NPK. Zinc increased N, P and K uptake and grain yield of maize plants. Foliar-applied Zn compounds are effective for increasing Zn, Cu and Fe uptake in corn. The optimal rate of zinc foliar spray for achieving significant grain yield response ranged from 1.0 to 1.5 kg Zn/ha as compared to the treatment fertilized only with NPK. Zinc treatment increased N, P and K uptake and grain yield (Mona, 2015)

A pot experiment was conducted to compare different organic manures with NPK fertilizer for improvement of chemical properties of acid soil. The results showed that application of 5 ton/ha of each of the evaluated organic manures and 100 kg/ha NPK 15-15-15 fertilizer improved chemical properties of both acid and nutrient depleted soils compared with unfertilized soil. Application of different types of organic manures reduced the acidic levels of both the soils. Application of different types of organic manures enhanced soil organic C, total N, available P, exchangeable K and CEC better than NPK fertilizer in both soils. Plant dry matter yield increased with application of NPK fertilizer compared with compost, poultry manure and cane rat droppings in both soils. In acid soil, application of NPK fertilizer gave the highest dry matter yield of 4.77 g/plant while in nutrient depleted soil; application of NPK fertilizer gave the highest dry matter yield of 5.58 g/plant (Adeniyan *et al.,* 2013).

It was reported that NPK 15:15:15 fertilizer rates have a profound effect on the overall performance of maize. Application of NPK fertilizer at the different levels used in this study had significantly effect on the growth and yield of maize. Fertilizer application level of 400 (60 kg N + 27.16 kg P + 49.80 kg K) kg / ha is effective for the optimum growth and yield of maize (Ogbomo and Ogbomo, 2009).

Ortiz *et al.,* (2009) evaluate the efficiency of a NPK fertilizer (8:15:15) with a Zn lignosulfonate (ZnLS) adhered as Zn source for maize plants. They compared the product in three experimental designs with the same NPK fertilizer with $ZnSO_4$ adhered and with no Zn adhered. In general, growth chamber experiments showed that plants treated with NPK + ZnLS presented the highest dry weight and Zn concentrations in shoots. Also at field experiments, the Zn concentration in shoots was significantly high in plants treated with NPK + ZnLS. The grain harvested showed that this treatment gave the highest values in one location, but in the other no significant differences were observed. Although further research is required, we can conclude that NPK + ZnLS product could be a suitable source of Zn for maize crops.

Zhong *et al.,* (2014) reported that conducted an experiment o evaluate the variances of soil physical and chemical, the contents of N, P and K in plant and maize grain yield. He reported that the soil bulk densities were increased, whereas the soil porosity, field capacity and pH values were decreased with more N application. Reasonable N fertilizer amount (241.5 kg/ha) and application at two stages (30% at sowing and 70% at jointing stage) could significant increase N utilization efficiency and improve maize yield.

Varghese and Ghosh, (2006) experimented the yield of maize cultivars (*Zea mays* L.) Durga hybrid and Jaunpur yellow with or without intercrop of urd (*Vigna mungo* L.) under two levels of fertilizers (120, 60, 60 and 140, 90, 70 kg NPK/ha) and reported that the maximum yield (60.41 q/ha) was found to be with hybrid maize intercropped with urd when fertilized with 140, 90, 70 kg NPK/ha. The number and weight of grains cob-1 and 1000 grain weight (248.9g) was also found to be maximum with 140, 90, 70 kg NPK/ha.

Khan *et al.,* (2014) investigated the response of maize variety (Jalal) to three phosphorus rates (60, 90 and 120 kg·ha^{-1}) and four nitrogen rates (90, 120, 150, 180 kg·ha^{-1}) for agronomical traits such as number of plant per m^2 (NP m^2), plant height (PH), number of leaves plant^{-1}(NLP), leaf area plant^{-1}·cm^2 (LAP), fresh weight of plants kg·ha^{-1} (FW) and dry weight of plant kg·ha^{-1} (DW). The results indicated that application of N @ 180 and P @ 120 kg·ha^{-1} significantly increased fodder yield of maize. The linear increase in biomass yield clearly indicated that N was a limiting nutrient factor and that N demand along with P has a positive response. At higher application rates, N fertilizer significantly increased biomass component, improved N uptake with increasing nitrogen use efficiency and decreased its losses to the environment and below plant zone.

Gong *et al.,* (2011) suggested that chemical fertilizer application could increase C renewal by increasing crop-derived C and accelerating original Soil Organic Carbon (SOC) decomposition, and that as long as a certain level of crop yield or aboveground biomass can be achieved, application of chemical fertilizer alone can maintain or increase SOC level.

Ojima et al, (1994) evaluated the short-term changes in plant production and microbial activity due to fire and the long-term consequences of annual burning on soil organic matter (SOM), plant production, and nutrient cycling. In the short-term, fire enhances microbial activity, increases both above-and belowground plant production, and increases nitrogen use efficiency (NUE). However, repeated annual burning results in greater inputs of lower quality plant residues causing a significant reduction in soil organic N, lower microbial biomass, lower N availability, and higher C: N ratios in SOM. Changes in amount and quality of below-ground inputs increased N immobilization and resulted in no net increases in N availability with burning. This response occurred rapidly (e.g., within two years) and persisted during 50 years of annual burning. Plant production at a long-term burned site was not adversely affected due to shifts in plant NUE and carbon allocation.

It was reported that nitrogen (N) deposition influences both above- and below-ground communities and influences ecosystem functioning. In this study investigated the responses of soil bacterial diversity to N enrichment at surface (0–10 cm) and sub-surface (10–20 cm) soils. N addition (>120 kg N ha^{-1} yr^{-1}) resulted in a significant shift in bacterial community composition and a decrease in bacterial OTU richness in surface soil, but the effect on the sub-surface layer was far less pronounced, even at the highest addition rate (240 kg N ha^{-1} yr^{-1}). Bacterial OTU richness was significantly correlated with soil and plant characteristics. The change in bacterial community composition was due to alterations in soil pH and plant composition. These results indicated that N fertilization directly affected soil bacterial richness but indirectly affected bacterial communities through soil acidification and plant community change, indicating distinct controls on soil bacterial diversity and community composition. It is also suggest that N availability could be a good predictor for the loss of soil bacterial diversity under atmospheric nitrogen deposition (Zeng *et al.,* 2016).

Adediran and Banjoko, (1995) conducted field trials on the response of maize to nitrogen (N), phosphorus (P), and potassium (K) fertilizers Nitrogen fertilizer as granulated urea at rates 0–300 kg N/ha, P fertilizer as single superphosphate at rates 0–120 kg P/h, and K fertilizer as muriate of potash at rates 0–180 kg K/ha were used for the different nutrient combinations. The base rates for N, P, and K were 100 kg N/ha, 40 kg P/ha, and 60 kg K/ha, respectively. The results indicated that annual application of the recommended N, P, and K rates to maize grown under intensive land use system could not produce optimum yield. The highest response by maize was to N, the optimum rate ranged from 50–100 kg N/ha. Application of high rates of P and K fertilizers on soils with fairly sufficient nutrient level showed no significant effect on maize yield. But when P and K were applied at low rates (20 kg P/ha and 30 kg K/ha), their contents in the leaf and maize yield, in most cases, increased significantly. It is recommended that the N, P, and K doses for optimum maize yield are 50–100 kg N/ha, 20 kg P/ha, and 0–30 kg K/ha, respectively.

Admas et al, (2015) investigated the effects of combined application of organic and inorganic fertilizers on yield and yield components and nutrient contents of maize, which were conducted on Nitisols (acidic soils) for two consecutive cropping seasons at northwestern highlands of Ethiopia. The experiments were laid down in RCBD as factorial combinations of three levels of N (0, 60 and 120 kg N ha^{-1}), compost (0, 5 and 10 tn compost ha^{-1}) and S (0, 15 and 30 kg S ha^{-1}). The highest mean grain yield, dry biomass, plant height, grain number per cob, cob weight, thousand seed weight, N concentration in leaf and grain (7.9, 22.4 t ha^{-1}, 2.52 m, 486, 0.44 g, 492 g, 3.25 and 1.4%) were observed in plots treated with fertilizer combinations of 120 kg N ha^{-1}, 10 t compost ha^{-1} and 15 kg S ha^{-1}, respectively. These studies showed that incorporation of compost with inorganic N and S fertilizers for maize enhanced grain yield by adding nutrients.

It was reported from the comparative study on the effect of organic manure (cow dung) and inorganic fertilizer (N.P.K) on the growth of maize (Zea Mays L.) that maize plants treated with N. P.K fertilizer were significantly taller than those treated with cow dung and those of control. Mean number of leaves, stem diameter, shoot and root dry weight were higher with N.P.K fertilizer but showed no significant difference (P>0.05) from those grown with cow dung manure. Growth indices of maize plants to which fertilizer N.P.K was applied showed no significant (P>0.05) increase than the cow dung. It is recommended that cow dung manure can be used in the absence of N.P.K fertilizer considering the cost and associated environmental effect of the later (Wisdom *et al.,* 2012).

It was also reported that from the study of comparative efficiency of organics and biofertilizers on growth and yield of maize (*Zea mays* L.) during Kharif season using maize cultivar Nithyashree (NAH 2049) shows that the treatment having recommended dose of NPK + Azotobacter chroococcum + Bacillus megaterium + Pseudomonas fluorescence + enriched compost has highest plant height at 30, 60, 90 days after sowing and at harvest (120 days) (31.70, 180.93, 186.07 and 188.13 cm respectively). The highest total dry matter production at harvest (375.80 g) and yield parameters like Weight of cob (207.63 g), Grain yield per plant (158.93 g), Grain yield per ha (54.53 q) and Test weight of seeds (33.10 g) was also found highest in this treatment and available nutrient content in soil after crop harvest i.e., nitrogen (185.40 Kg ha^{-1}), phosphorous (38.83 Kg ha^{-1}) and potassium (181.47 Kg ha^{-1}) was also found highest in the same treatment combination (Umesha *et al.,* 2014).

From an experiment conducted to compare the effect of three different tillage regimes i.e. deep, conventional and zero and four fertilizer levels viz., control 100-50-50, 150-75-75 and 200-100-100 NPK kg ha^{-1} on the spring maize, Memon *et al.,* (2013) reported that there was significant differences in maize emergence percentage, plant height, grains cob^{-1} , 1000-grain weight and grain yield due to tillage practices and various fertilizer levels, between tillage practices. However, the NPK ratio of @ 200-100-100 kg ha^{-1} and deep tillage produced the highest emergence percentage, plant height, grains per cob, 1000-grain weight and grain yield followed by other fertilizer levels and conventional tillage. The zero tillage plots produced the low emergence percentage, plant height, grains cob^{-1} , 1000-grain weight and grain yield. Therefore, considering the environmental conditions, the deep tillage with recommended dose of NPK performed best and provided more vegetative growth and grain yield in maize. However, poor-resource farmers can use the medium level of NPK ratio of 150-75-75 kg ha^{-1} for getting an economical and successful maize crop.

2.3 Effect of Spacing on maize

It was reported that from the evaluation of three hybrid maize varieties under three different plant spacing for such growth characters as plant height and number of leaves. The results obtained 60 days after sowing indicated that hybrid variety 9022-13 which had mean plant height of 170.0cm and number of leaves of 13.2 was superior to other varieties investigated. With respect to spacing, plants sown on 75 cm x 15 cm had higher mean height and number of leaves of 176.7 cm and 13.8, respectively which interplay to improve grain yield of maize. (Enujeke, 2013)

It was reported that the steady decline in maize yield can be attributed to rapid reduction in soil fertility caused by intensive use of land and reduction of fallow period (DIPA, 2006), failure to identify and plant high yielding varieties most suited or adapted to each agro-ecological zone (Kim, 1997) and use of inappropriate plant spacing which determines plant population and final yield (Zeidan *et al.,* 2006).

Iken and Anusa, (2004) recommended an optimum plant population of 53,333 plants/ha for maximum yield of maize and indicated that this is obtainable using a spacing of 75cm x 25cm at 1 plant per stand or 75cm x 50cm at 2 plants per stand. Azam *et al.,* (2007) reported that spacing of 75cm x 35cm resulted in increased grain yield of maize while 75cm x 15cm gave maximum cob weight.

Similar report by Allessi and Power (2004) revealed that maize cob weight decreased with increased plant population.

The high sand content of the soil could be attributed to high content of quartz in the parent material (Brady and Weils, 1999). The weakly acid nature of the soil of the area may be traced to the marked leaching of exchangeable bases resulting from the high rainfall associated with the environment and the dissociation of strong and functional group in the organic matter (Esu, 2001).

The low organic matter status of the soil could be attributed to the rapid decomposition of organic matter due to high solar radiation and moisture, these favour optimum microbial activities in the soil. It could also be attributed to the annual seasonal bush burning which tend to deplete organic matter accumulation in the soil (Landor, 1991).

The low level of total nitrogen could be possibly due to low organic matter content of the soil which contributes about 90-95% of soil nitrogen. It could also be attributed to leaching of nitrate by torrential rainfall prevalent in the environment (Olatunji *et al.,* 2007).

The high level of Phosphorus may be attributed to either the history of land use and cultural practices associated with the land use that do not take much P nutrient from the soil and the application of P organic or inorganic fertilizers (Nnaji, 2008) or the parent material from which the soil was formed may be rich in P minerals (Brady and Weils, 1999) or the soil may not be highly acidic as to cause high level of P fixation (Brady and Weils, 1999; Omokri *et al.,* 2007).

It was reported that maize plants spaced 15cm grew taller than other plants possibly because of increased competition for space, sunlight and available nutrients (Teasdale 1995; Widdicombe and Thelen 2002). The increased growth rates and earlier canopy closure of narrow row spaced crops is also attributed to quest for increased light interception as well as increased availability of soil moisture because of equidistant distribution of crop plants (Dalley *et al.,* 2006).

Ali *et al.,* (2003), observed that maize plant sown on 15cm spacing had higher number of leaves than their counterparts which were sown at wider spacing possibly because of increased growth rate in search for space, sunlight and other environmental resources. He also reported that competition between maize plants for light, soil fertility and other environmental factors were markedly increased with highest population but decreased with lower plant population.

It was investigated that maize plant population of 40000 ha^{-1} produced maximum number of kernels per row (32.33). However, 60000 plants ha–1 produced the maximum number of biomass yield (16890 kg ha^{-1}) and grain yield (2604 kg ha^{-1}). Therefore, planting density of 60000 plants ha–1 (plant to plant distance of 22.70cm) is recommended for obtaining higher yield of maize (Abuzar *et al.,* 2011).

The plant populations of maize affect most growth parameters even under optimal growth conditions and therefore it is considered a major factor determining the degree of competition between plants (Sangakkara *et al.,* 2004). The grain yield per plant is decreased in response to decreasing light and other environmental resources available to each plant (Luque *et al.,* 2006). Stand density affects plant architecture, alters growth and developmental patterns and influences carbohydrate production. The use of high population increases interplant competition for light, water and nutrients, which may be detrimental to final yield because it stimulates apical dominance, induces barrenness, and ultimately decreases the number of ears produced per plant and kernel set per year (Sangoi, 2001).

It was reported that row spacing, were affected on plant dry weight, dry ear weight, dry leaf and dry stem weight. While the silage yield, ear yield, leaf yield, plant dry weight and dry ear weight, were affected by nitrogen and showed significant difference. Potassium had significant difference on plant dry weight, dry leaf and dry stem weight. The most silage yield (42/23t/ha) and dry plant weight (13.88 t/ha)obtained from 65cm row spacing that dry plant weight had significant difference with other row spacing. Amount of 450kg/ha nitrogen was caused the most silage yield (41/6t/ha) and plant dry weight (13.36 t/ha) that had not significant difference with usage of 350kg/ha nitrogen. The most silage yield (40/75t/ha) obtained from 200kg/ha potassium that had not significant difference with other potassium usage levels. The most plant dry weight (13.36) obtained from 150kg/ha potassium that had not significant difference with 200 kg/ha potassium usage levels (Rezaeian *et al.,* 2014).

Sangoi *et al.,* (2001) reported that the reduction of row spacing from 100 to 50 cm increased linearly maize grain yield. The yield edge provided by narrow rows was higher when maize was sown earlier in the season. Differences in hybrid cycle and plant architecture did not alter maize response to the reduction of row spacing.

Decreasing the distance between neighbor rows at any particular plant population has several potential advantages. First, it reduces competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement (Olson and Sander, 1988; Porter *et al.,* 1997). The more favorable planting pattern provided by closer rows enhances maize growth rate early in the season (Bullock *et al.,* 1988), leading to a better interception of sun light, a higher radiation use efficiency and a greater grain yield (Westgate *et al.,* 1997). Secondly, the maximization of light interception derived from early canopy closure also reduces light transmittance through the canopy (McLachlan *et al.,* 1993). The smaller amount of sun light striking the ground decreases the potential for weed interference, specially for shade intolerant species (Gunsolus, 1990; Teasdale, 1995; Johnson *et al.,* 1998). Thirdly, the quicker shading of soil surface during early part of the season results in less water being lost by evaporation (Karlen and Camp, 1985).

Maize plant with inter-row spacing of 0.75m, 0.90m, 1.05m, 1.20m, 1.35m, and 1.50m, with the intra-row spacing of 0.30m, 0.40m and 0.50m were observed and investigated that the plant height, number of grains per cob, one thousand grain mass, number of cobs per plant, cob length and grain yield increased with decrease in plant density. Plant density significantly affected plant height, number of grains per cob, one thousand grain mass, cob length and grain yield. The highest grain yield of 2779.80 kg/ha was produced at 16,670 plants ha^{-1} and the lowest grain yield of 1073.30 kg/ha was produced at 44,440 plants ha^{-1} (Mashiqaa *et al.,* 2012).

Plant density is dependent on both row width and intra-row spacing, and under dry land conditions row width plays an important role in determining plant density. Intra-row spacing should not be too narrow as this can increase competition between plants and results in yield detrimentally affected. However, under optimum water and nutrient supply, high plant density can result in an increased number of cobs per unit area, with eventual increase in grain yield (Bavec and Bavec, 2002). Liu *et al.,* (2004) reported that maize yield differs significantly under varying plant density levels due to difference in genetic potential.

Lyock *et al.,* (2013) showed that the intercropped maize irrespective of spacing adopted, were consistently superior to the sole maize crop in dry matter production per plant, height per plant, number of leaves per plant and leave area per plant. The best grain yield of 3.78 tonnes/ha was obtained in maize spaced at 75 x 75 cm. The sole ginger crop gave rhizome yield (14.08 tonnes per hectare) was statistically higher than yields obtained in intercropped treatments. The intercropped treatments had yield advantages over the sole crop with maize Land Equivalent Ratio of 23-79%. Therefore, maize at 75 x 75cm in ginger at 20 x 20cm was recommended as the best intercrop.

Fanadzo *et al.,* (2010) reported that plant population with narrow rows of 45 cm reduced weed biomass by 58%. Growing maize at 40000 plants ha^{-1} resulted in similar green cob weight regardless of inter-row spacing. Cob length decreased with increase in plant population and with wider rows. Similar grain yield was obtained regardless of inter-row spacing when maize was grown at 40000 plants ha^{-1}, but at 60000 plants ha^{-1}, 45 cm rows resulted in 11% higher grain yield than 90 cm rows. Increasing plant population from 40000 to 60000 plants ha^{-1} resulted in a 30% grain yield increase. The study demonstrated that growers could obtain higher green and/or grain yield by increasing plant population from the current practice of 40000 to 60000 plants ha^{-1} and through use of narrow rows.

According to Fanadzo, (2007), provided nutrients and moisture are not limiting, successful cultivation of maize depends largely on the efficacy of weed control. Weed induced losses are highest in smallholder farming and can be as high as 99% in maize Poor weed control decreases water and nitrogen use efficiency, the two most important inputs to achieving high yields under irrigation (Thomson et al., 2000).

Liang Yi *et al.,* (2009) reported that the population structure was improved effectively under wide and narrow row cultivation and the micro-environment of canopy was improved, the central canopy of light transmission rate was increased, the competition among individuals were less, the growth of individuals were better, dry matter accumulation and LAI was increased. This form improved the initial quantum efficiency of ear leaf, to impel the leaves get the effective utilization on weak light, and improved the photosynthetic performance of maize leaves, thus make the yield of maize was improved.

Koli, (1971) reported that increasing the plant population to 21780 per acre gave highly significant yield over the current adopted 14520 plants per acre. Generally the higher populations gave the higher yields. Fertilizer application also increased yields over the control, but high fertilizer rate was not beneficial. The weight of cob per plant decreased with increasing population. Fertilizer application increased yield but not significantly. Perhaps it may be more advantageous, in the forest zone, to use closer spacing such as 2 ft x 1 ft on a fertile land as the evidence suggests that in a year with fair rainfall distribution, and with planting done at the optimum time, the increase in yield over wide spacing might be highly significant.

Ibeawuchi *et al.,* (2008) reported that the highest dry maize grain yield was obtained in the hybrid varieties using plant spacing of 25 x 75cm while the lowest yield was obtained in the local maize type with plant spacing of 100 x 100cm. The trend observed in the other plant attributes measured such as the plant height and the Dry Matter Accumulation (DMA) showed that the hybrid maize varieties performed significantly better than the local ones and had higher nutrient efficiency and conversion rate than the local cultivars although the yield was predicated on plant population. It was also recommended that maize sole using plant spacing of 25 x 75cm was the best recommendation for optimum maize grain yield in the field and an improvement of the local maize cultivars genetically for sustainability and food security purposes.

The experiment conducted with the maize hybrids Pioneer 3025, Cargill 707, Cargill 922 and Baber using plant to plant spacing of 15, 25, 35 and 45cm showed that number of cobs per plant, cob weight, grain yield (kg ha^{-1}) and harvest index were significantly affected by hybrids. Hybrid Pioneer had significantly higher number of cobs plant^{-1} (1.14), cob weight (324g), grain yield (3275kg ha^{-1}) and higher harvest index (24) as compared with other hybrids. Various spacing had significantly affected cobs/m², grains cob m^{-1}, cob weight and biological yield while the effect on other parameters was non-significant. Spacing of 15cm had significantly more number of cob per m² (10), lower grains cob^{-1} (343), lowest cob weight (227g) but higher biological yield (15691kg ha^{-1}). Interaction of hybrid Pioneer and 25cm give highest grain yield ha^{-1} (Azam *et al.,* 2007).

The experimental result of the photosynthetic characteristics, chlorophyll fluorescence parameter and yield of waxy maize under the different planting densities indicated that the planting density of 6.00×104 plants/hm^2 was beneficial to the improvement of Pn,ε,Fv/Fm,ΦPS and qP; and reduction of Rd and NPQ. The ratio of maize kernel at higher level showed significant to the planting density affecting the photosynthetic characteristics, chlorophyll fluorescence parameter and yield of waxy maize and there was positive relationship between the photosynthetic characteristics of the population and maize yield (Wei, 2009).

The study of Jinhai 5 and compact maize Zhengdan 958 showed that with the increasing of density, plant height was increased, stem diameter and ear diameter was decreased, ear was shorten, rare top length, No. of ear nod, ear height was increased, brace root number and total root number was decreased, the rate of root dry weight was increased within farming layers, population dry matter accumulation was increased and plant dry matter accumulation presented the opposite trend, ear linage, kernels per ear,100-kernels weight, double-ear rate, plant yield was decreased, yield was increased and decreased successively. The relation between yield and density of Jinhai 5 was $Y=-625.67x2+9\ 044.5x-18\ 530$,optimal plant density was 7.0×104-7.5×104 plants/ha, the relation between yield and density of Zhengdan 958 was $Y=-375.67x2+6\ 410x-13\ 043$,optimal plant density was 8.5×104-9.0×104 plants/ha. It was also revealed that the number of brace roots and total roots could be used as an indicator for plant dry weight and yield (Li *et al.,* 2008).

The study on the effects of density on photosynthetic physiological characteristics and yield of maize with Langyu No.6 and Nongda 108 showed that chlorophyll content , soluble protein content and dry weight per plant dropped by density increasing, leaf area index, population dry weight, leaf area duration and crop growth rate increased with increasing density. The effect was more significant in post-stage than that in earlier-stage. The response to density of Langyu No.6 was more slowly than that of Nongda 108, both single plant and population characteristics, which showed that Langyu No.6 density-resistant was more tolerance than Nongda

108. The suitable planting density of Langyu No.6 and Nongda 108 were 67 500 plants/ha and 60 000 plants/ha respectively. (Ming *et al.,* 2007)

Jing *et al.,* (2009), reported that the population structure of maize was improved effectively under wide and narrow row cultivation, and the micro-environment of canopy was improved, the central canopy of light transmission rate was increased, the competition among individuals were less, the growth of individuals were better, dry matter accumulation was increased. This form improved the initial quantum efficiency of ear leaf to impel the leaves get the effective utilization on weak light and improved the photosynthetic performance of maize leaves, thus make the yield of maize improved.

The three plant population densities (6.75×104, 8.25×104, 9.75×104 plants/ha) of two summer maize cultivars DH618 and DH605 showed that planting density had a marked improvement on canopy apparent photosynthesis, canopy photosynthesis ability and grain yield which ensure the accumulation of photosynthetic products. Nevertheless net photosynthesis rate decreased along with the density increased. DH618 had a higher grain-yield than DH605 under the condition of 10 days early harvest. Both the two cultivars reached maximum production under the density of 97 500 plant/ha, 13 840 kg/ha and13 080 kg/ha, respectively. Besides, lodging rate of DH605 was dramatically higher than DH618 (Wang *et al.,* 2015).

Early studies indicated that improved plant spacing uniformity has no significant effect on grain yield (Erbachetal.,1972; Muldoon and Daynard,1981). In contrast, other research has demonstrated that non-uniform plant spacing may reduce grain yield. Krall *et al.,* (1977) reported a significant decrease of 84 kg ha-1 in grain yield for each centimeter increase in SD of plant spacing. Vanderlip *et al.,* (1988) found that grain yields decrease when SD values exceeded 6 cm. Nielsen (2001) stated that corn grain yields decrease an established average of 62 kg ha^{-1} for each centimeter increase in SD of plant spacing when SD is greater than 5 cm. He also reported that the rate of yield loss with increasing SD is not constant but varies among locations in Indiana from 30 to 110 kg ha^{-1}. A more recent on-farm study undertaken by Doerge and Hall (2001) indicated an average increase in grain yield of 84 kg ha^{-1} for every centimeter improvement in SD of within-row plant spacing.

According to Muranyi (2015), the optimal plant densities of the hybrids were different in the two studied crop years: in 2013, regarding the treatments set with the row distance of 45 cm, increasing plant densities resulted in higher yields, while in 2014, the yield showed decreasing tendency parallel to the increasing plant densities, that is confirmed by the fact that plant densities of 50 000 and 65 000 plants ha-1 proved to be more favourable. Regarding the treatments with a row distance of 76 cm, hybrids obtained their yield maximums by 80 327 plants ha^{-1} in 2013, while in the vegetation of 2014, by higher plant density (85 845 plants ha^{-1}).

Roekel and Coulter, (2011) determined a close relationship between maize yield and plant density. The studied hybrid produced maximal yield by a plant densities of 81 700 plants ha^{-1} or even higher. Berzsenyi and Lap, (2005) have also found that optimal plant density varied between 67 483 and 70 161 plants ha^{-1} regarding the average of the involved hybrids. According to Shapiro and Wortmann (2006) a yield increment of 4% could be produced by decreasing the row distance from 76 cm to 51 cm. Mohseni *et al.,* (2013) confirmed that the increase of plant density from 60 000 plants ha-1 (9.09 t ha-1) to 80 000 plants ha^{-1} (11.14 t ha^{-1}) resulted in a yield increment as well.

Norwood, (2001) reported in hybrid corn that early sowing (April 17) with population of 60000 plants ha^{-1} gave lowest yield (22.1 q ha^{-1}) compared to lower population 30000 plants ha-1 (23.2 q ha^{-1}). Similarly under late sowing (May 6) with a population of 60000 plant ha-1 gave higher yield (40.2 q ha^{-1}) as compared to 30000 plants ha^{-1} (26.9 q ha^{-1}).

Lauer and Rankin, (2004) similarly measured the response of plant grain yield to spacing variability, and attempted to determine if there exists a common threshold where variability begins to affect that yield. Data was collected over 24 Wisconsin environments from the years 1998 to 2000. From which, they observed that the standard deviation of plant spatial variability typically ranged from 4 to 17 cm. Their repeated deviating spacing patterns indicated that exceeding a 95% confidence interval range of 9 to 14 cm incurred by-plant yield reductions. They too agree that the term standard deviation does not always convey a meaningful assessment of a stand's composition regarding how the uniformity variations were created. However, they stated that the plant spacing variability typically observed in a producer's fields does not significantly alter overall grain yield.

Liu *et al.,* (2004) examined the hypothesis absolute plant spacing uniformity is required to achieve maximum corn yield potential at their research stations in Ontario. To create spacing non-uniformity, Liu *et al.,* (2004) planted mixtures of Roundup Ready and conventional corn at 69100 plants ha^{-1}. Stands were thinned with a glyphosate, [N-(phosphonomethyl) glycine], application at the vegetative stage V3 resulting in spacing standard deviation values from 6 to 16 cm.

When their data was combined over both locations and years, researchers observed no 20 significant grain yield response due to within row spacing variability. Numerically compared to their “6 cm” control treatment, the slope coefficient of regression indicated a grain yield decrease of 32.5 kg ha^{-1} for each 1 cm increase in spacing deviation. Multiple regression analyses determined that short and long gaps, doubles and skips explained 77% of the variance in plant spacing standard deviation. Furthermore, they determined each plant-to-neighbor arrangement’s contributable weight to the spacing standard deviation values which follow: long gap > multiple plant clusters > short gap > doubles.

Martin *et al.,* (2005) studied by-plant yield variation instead for on-farm production environments ranging from Argentina to Nebraska. The data collected described plant-to-plant 21 grain yield in terms of standard deviation, coefficient of variation, and yield range. Their results showed that the standard deviation of corn plant productivity increases with increasing final yields; however, the coefficient of variation for those consecutive within-row plant yields was negatively correlated with mean grain yield. The range of by-plant yields also increased with average corn grain yields. Researchers proposed that the common components that create within-row stand variability (planting depth, tillage, compaction, moisture, etc.) also influence plant-to-plant productivity variations. Their research also suggests that precision yield monitors are limited in their ability to accurately describe yield variability over a large standing area. Furthermore, yield may then only be averaged over 0.5 to 0.6 meters of row length, so as to adequately describe the variation of by-plant yields.

Hashemi *et al.,* (2005) examined how crowding stress, resultant to field populations and variable within-row spacing, influenced the response of corn yield and its components. Their study was conducted during 1986, 1987, 1998, 1999 and 2000 at locations in Massachusetts and Iran. Hybrids were overplanted and hand thinned to densities ranging from 2 400 to 120 000 plants ha-1. Crowding comparisons were made against the lowest planted population as it was assumed to lack any measurable plant-to-plant competition. Kernel weight declined as population increased from 30 000 to 120 000 plants ha-1 between 9 and 21%; however, as population increased, the decline in yield was mostly due to kernel number reduction. The harvest index measurements indicated that plant-to-neighbor crowding had little influence over assimilate partitioning. Their research concluded that plant-to-plant competition occurring at V5 to anthesis and anthesis to grain filling had the greatest negative effect on final grain yield (8 to 21% and 6 to 22%, respectively).

As with stand density, nitrogen fertilization is a management factor that markedly affects corn crop development. Research by Rossini *et al.,* (2011) in Argentina sought to describe the influence that stand densities and variable N-rates have over development regarding plant growth rates, ear growth rates and number of kernels per plant during the early-reproductive and silking development stages. Two hybrids, defined by their crowding tolerance, were cultivated with different combinations of stand density (60 000, 90 000 and 120 000 plants ha-1) and N supply (0 and 200 kg. of N ha-1 fertilized at V6). Analysis of their density by contrasting Nitrogen-supply response data indicated that increasing crowding and competition for limited resources causes reductions to plant biomass and kernel number per plant (39 to 72% loss of kernel number). Interestingly, fertilization with Nitrogen reduced plant-to-plant variations in kernel number and biomass partitioning, suggesting that this management practice could reduce the effects provoked by accidental non-uniformly spaced plant stands.

Chapter – III

STUDY AREA

3.1 Geographical location

3.1. Mizoram

With a geographical area of over 21,087 Sq km and perched on the high hills of the North Eastern part of the country, Mizoram possibly has the most difficult terrain, over 80% of the total geographical area being hilly and with steep hills separated by rivers flowing North to South, thus, creating innumerable hurdles in intra- state as well as inter-state communication. This landlocked area is bounded by foreign countries on all sides except for a small stretch that rubs shoulder with Assam, Manipur and Tripura. Its international border, which is about 722 km, is almost 3 times longer than its border with the mainland. Mizoram lies between $21^0$30'N – $23^0$15'N Latitudes and $92^0$16'E – $93^0$26'E longitudes (Rintluanga, 1994). Mizoram is bounded on the North side by Cachar district of Assam and Manipur state; on the East and South by Chin hills of Myanmar; on the west by Chittagong hill tracts of Bangladesh and Tripura.

The state is divided into eight administrative districts, *viz*., Aizawl, Champhai, Kolasib, Mamit, Lunglei, Serchhip, Lawngtlai and Saiha (Fig.3.1). About 57.8 percent of the population depends on agricultural products and practice jhum cultivation (Anon., 2004a). As per 2011 census, Mizoram has recorded a population of 1,091,014 consisting of 552,339 males and 538,675 females, a sex ratio of 975 females to 1000 males.

Figure 3.1: Map of the districts in Mizoram State showing the location of Aizawl city.

The topography of Mizoram is, by and large, mountainous with precipitous slopes forming deep gorges culminating into several streams and rivers. Almost all the hill ranges traverse in the North – South direction. The eastern part of Mizoram is at a higher elevation compared to the western part. The average height of the hill ranges is around 920m, although the highest peak, the Blue mountain (Phawngpui) goes up to 2165m.

3.1.2 Aizawl

Aizawl is the capital as well as the largest city of Mizoram. It is located north of the Tropic of Cancer in the northern part of Mizoram and is situated on ridge 1132 m (3715 ft) a.m.sl., with the Tlawng river valley to its west and the Tuivawl river valley to its east. Summer temperature ranges from 20 – 30oC, and winter 11 – 21oC. The geographical area of Aizawl is 3,576 sq km and as per the 2011 census a population of 404,054.

3.2 Climate and weather

3.2.1 Mizoram

Mizoram enjoys a moderate and pleasant climate. The temperature varies from 9^0C to 24^0C during winter and 24^0C to 32^0C during summer. The climate is pleasant in the months of October and November (19^0C to 25^0C). The upper part of the hills are predictably cool, during the summer, while the lower reaches are relatively warm and humid. Storms break out during March- April, just before or around the summer. The entire Mizoram comes under the direct influence of the South west monsoon receiving an annual average rainfall of 2095mm in the year 2009. The rainy season normally starts from June and continues up to September and the rainfall is more or less evenly distributed throughout the state excepting the South-western parts that generally receives slightly higher rainfall (Anon., 2011).

3.3 Soils

3.3.1 Mizoram

The soils of Mizoram are dominated by sedimentary formation. These are generally young, immature, mostly developed from parent materials such as fereginous sandstones and shale. The soils of Mizoram are classified into three orders such as ultisols, inceptisols and entisols (Sarkar and Nandy, 1976; Singh and Dutta, 1989). The soils in the hills are collocium deposit and in plain areas alluvial deposits are predominant. The soils as a whole are well drained except in few valley flat lands. The soils in general have low inherent fertility *viz*. bases and mineral reserves. The soils in the hills are strongly acidic in reaction, whereas the soils in alluvial deposits are less acidic in nature (Anon., 1991a). Analysis of soil samples from different places in Mizoram indicates that available manganese, copper and iron are adequately available except zinc. (Anon., 2004b).

The surface soils of the hilly terrains of Mizoram are dark, highly leached and poor in bases, rich in iron and acidic with pH values ranging from 4.5 to 6.0. The soils are well-drained, deep to very deep, rich in organic carbon, low in available phosphorus content and high in available potash. The surface soil textures are loam to clay loam clay content increasing with depth. The percentage of clay, silt and sand within 50cm of the surface in most cases are 20-30 percent and 25-45 percent respectively. The pH and organic C content mostly decrease with depth. The base saturation above a lithic or paralithic contact is mostly is low which is below 35 percent (Anon., 1991a). They are capable of providing substantial oxygen supply for plant growth and have capability to retain moisture and maintain supply through the growing seasons of most crops.

3.4 Forest and vegetation

3.4.1 Mizoram

The state of Mizoram falls under the tropical semi-evergreen belt. However, due to reduced jhum cycles it is replaced by bamboo interspersed with secondary forests. The state is divided into 12 forest divisions falling under three territorial circles. The forest 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 *bona fide* locals to meet their needs (State of Forest Report, 2006).

The forests are divided into Protected areas, reserve forest and unclassified forests. 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 km^2 (ISFR, 2011). The reserved- forest covers 6465 km2 and the Protected forest coves 941 km^2 (Anon., 2008a).

Various authors have classified the vegetation of the state. Based on Champion and Seth's classification (1968) the following types of forest are found to be present in the state:

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

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

(c) Montane sub-tropical pine forests (1500-2158 m)

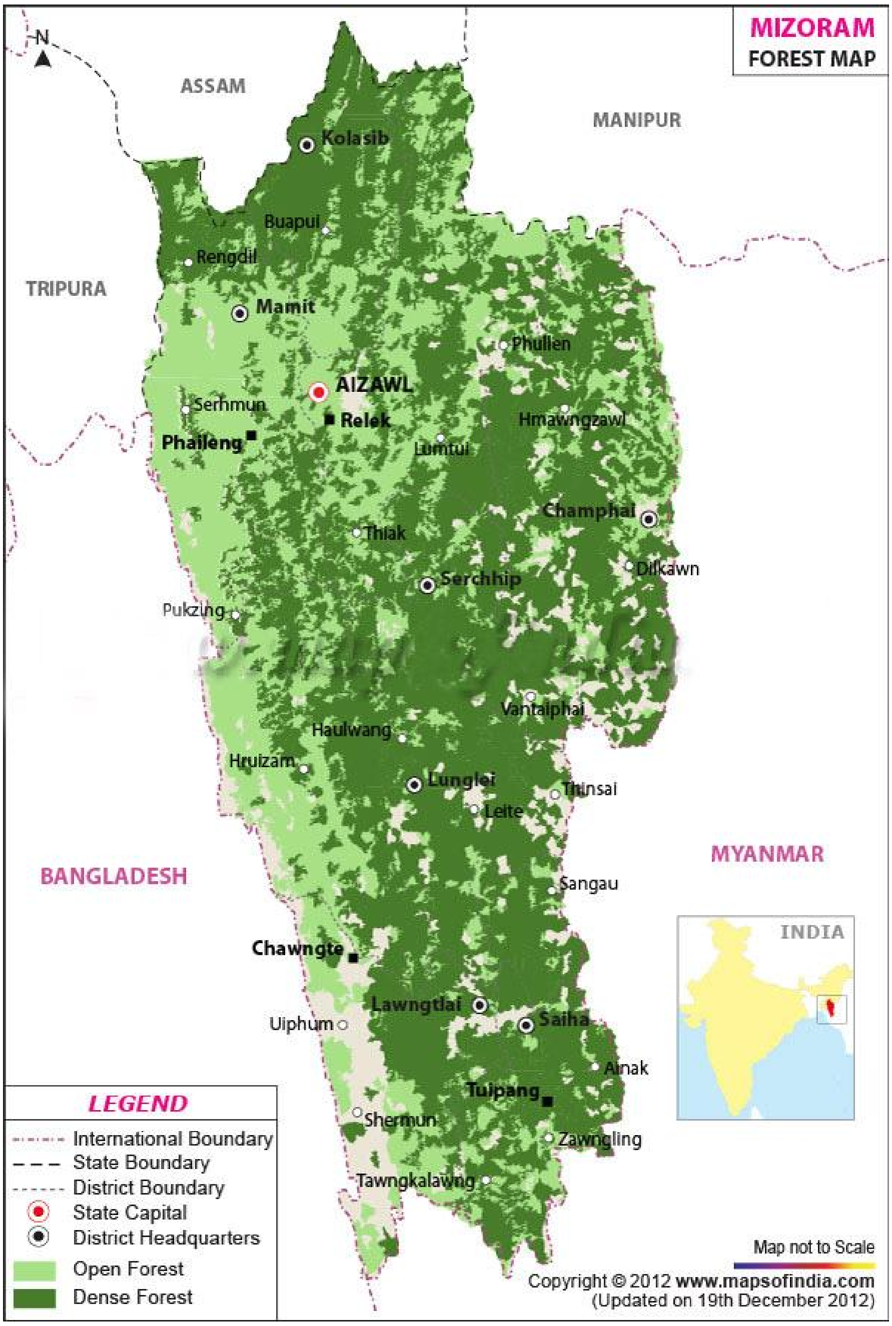

Figure 3.4: Map of Mizoram State showing open and dense forest. (ISFR, 2011)

Tropical Wet -Evergreen forests are found in the Southern and Western parts of Mizoram. The common timber species found in these areas are *Dipterocarpus turbinatus*, *Artocarpus chaplasa*, *Terminalia myriocarpa*, *Duabanga sonneratoides*, *Michelia champaca* growing in association with undergrowth (Anon., 2003).

Tropical semi-evergreen covers the central bio-geographic zone and the coverage is approximately 50 percent of the total geographic area. The common tree species are *Michelia champaca, Schima wallichi, Gmelina arborea, Catanopsis tribuloidies* etc. Bamboo species like *Melocanna baccifera* and Dendrocalamus species and canes are abundant, especially in shady and low lying areas (Anon., 2003).

The Montane sub-tropical pine forest occurs in the eastern fringes bordering Myanmar and constitutes about 24 per cent of the total geographical area. The common tree species are *Pinus kesiya, Rhododendron arboretum, Quercus serrata, Quercus griffithii*, etc. (Anon., 2003).

3.5 Landuse Pattern and cropping system in Mizoram

Land within Mizoram, like some other states of North east, is in the customary ownership of the communities. Village lands falling within the jurisdiction of villages are controlled by the Village Council (s) and land distribution is done as per the customary practice to the villagers for jhumming and other farming activities. The landuse pattern of the state has been affected primarily by land capability as determined by characteristics of micro and mini watersheds. Besides, several social legal factors such as land tenure system etc. also affect the landuse pattern.

Agriculture is the main stay for about 60 per cent of the population of Mizoram. Of the total area only 21 per cent is put on the paddy/ seasonal crops. As high as 63 per cent of the total crops area is under jhum cultivation. The crops grown in the jhum are mixed. The principal crop is paddy and others are maize, cucumber, beans, arum, ginger, mustard, sesame, cotton etc. There is vast scope for cultivation of tapioca, sugarcane, cotton, pulses and oil seeds in the State. Oil seeds crops like sesame, mustard and soyabean are growing well in the state. Paddy occupies almost 50 per cent of the total cropped area and more than 88 per cent of the total area under food grains (Anon., 2010).

CHAPTER IV

MATERIALS AND METHODS

4.1 Experimental Site

The experiment was conducted at Edenthar area which is at the outskirt of Aizawl, the capital city of Mizoram State. The altitude is about 493m from MSL with geographical coordinates of 23.754149° N and 92.714610°E. The hill slopes have the soil orders of ultisols with sandy clay loam texture. The average annual rainfall in this area is 2150 cm. The experiment was carried out in the month of March to July in the year 2010. The surface soils are dark, highly leached and poor in bases, rich in iron. pH and organic carbon content decrease and clay content increases with depth.

4.2 Experimental Design and treatments

The experiment was designed using Randomized Block Design (RBD) with three replications. There was 12 sub-plots and each of the sub-plot was 4m x 3m (12 sq.m) and each sub-plot is separated by 1 metre width buffer zone. Each replication covered an area of 210 sq. metre.

Experimental Design : Randomized Block Design. (RBD)
No.of Replications : 3 (three)
Sub-Plot size : 4m x 3m (12 sq.m)
No.of Sub-Plots : 12 sub-plots under each replication (36 nos.)
Area of one plot size : 210 Sq.m
Area of total (3) plot size : 630 sq.m
Crop species : *Zea mays* L
Treatments : 12 treatments

4.3 Experimental Layout

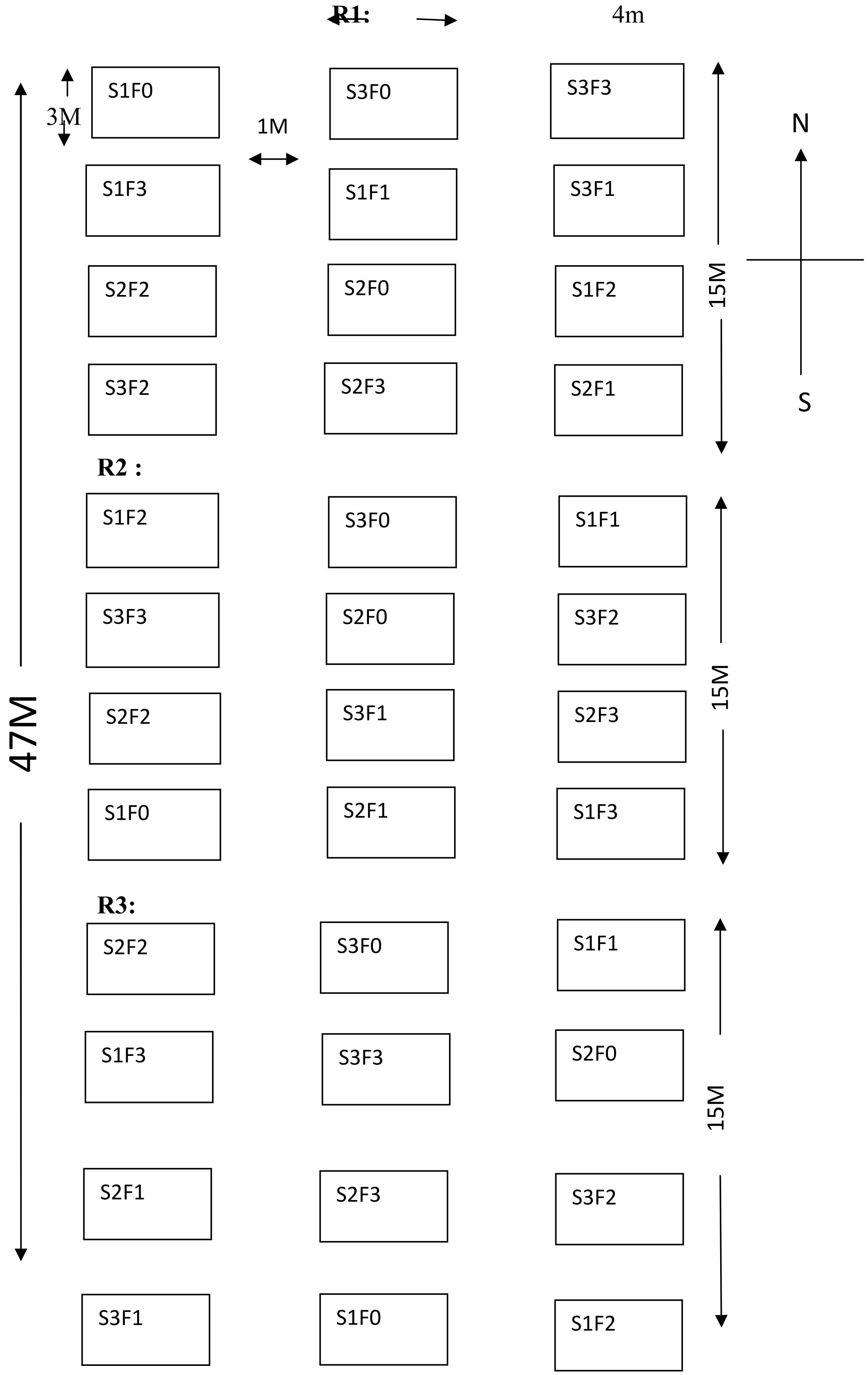

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Figure 4.1: Location of the experimental site at Edenthar showing the treatment plots of the experimental block.

4.4 Treatment details

Three jhum cycle sites viz. 2 years jhum cycle (2JC), 3 years jhum cycle (3JC) and 5 years jhum cycle (5JC) were selected, which located adjacent to each other within an area of 2 acres to rule out the difference in environmental parameters. Three levels of nitrogen (N), phosphorus (P) and potassium (K) fertilizer doses and control (without NPK) were applied against three different spacing as table below:

Table 4.1: Table showing combination of spacing and fertilizer treatment plots

Fertilizer Treatment	NPK Doses (kg/ ha)			Spacing Treatment	
	N	P	K	Row to row	Plant to plant
S1F0	0	0	0	55	20
S1F1	80	40	20	55	20
S1F2	100	50	30	55	20
S1F3	120	60	40	55	20
S2F0	0	0	0	75	20
S2F1	80	40	20	75	20
S2F2	100	50	30	75	20
S2F3	120	60	40	75	20
S3F0	0	0	0	60	25
S3F1	80	40	20	60	25
S3F2	100	50	30	60	25
S3F3	120	60	40	60	25

4.5 Application of NPK fertilizer

A mixture of Urea (N), Single Super Phosphate (P) and Muriate of Potash (K) is applied in the field in three different doses such as 120, 60, 40 kg/ha; 100, 50, 30 kg/ ha; 80, 40 20 kg/ha respectively at two split doses in the field before tillering and after sowing.

4.6 Details of collection of Data

4.6.1 Soil sample collection

Prior to land preparation soil samples were collected from 12 locations in each replication from three jhum cycle sites by using spade from a depth of 0- 30 cm on one day before the start of the experiment . Soil samples were collected and packed in the polythene bag. The three jhum plots were slashed and burnt before the experiment. The soil samples were serially registered giving all the necessary information mentioning the sample number, place of collection, depth of collection of samples and site description.

4.6.2 Processing of soil samples

The soil samples were air dried and crushed and passed through sieves of finer mesh size (Ghosh *et al.,* 1983).

4.6.3 Determination of pH

The pH of the soil samples was measured by the method of soil to water ratio of 1:2. Soil samples of 20 g was taken in a 100 ml beaker to which 40 ml of water was added. The suspension was stirred at regular intervals for 30 minutes and the pH was recorded with the help of pH meter.

4.6.4 Estimation of Organic Carbon

The method given by Walkley and Black (1934) was adopted to estimate Organic Carbon. Soil samples were grounded and completely passed through 0.2mm sieve and 1.00g of it was kept at the bottom of a dry 500ml conical flask. Then 10ml of 1N $K_2Cr_2O_7$ was pipetted in and swirled a little. The flask was kept on asbestos sheet. Then 20 ml of H_2SO_4 (containing 1.25% Ag2SO4) was run in an swirled again two or three times. The flask was allowed to stand for 30 minutes; thereafter, 200ml of distilled water was added. Thereafter, 10ml of phosphoric acid or 0.5g Sodium fluoride and 1ml of diphenylamine indicator was added and titrated with ferrous Ammonium Sulphate solution till the colour flashes from the blue violet to green. Simulteneously, a blank was run without soil. The result was calculated by the following method:

$$\text{Organic Carbon (\%)} = \frac{10(B-T) \text{ x } 0.003}{B} \text{ x } \frac{100}{\text{Wt. of soil}}$$

(Where B= Volume (in ml) of ferrous ammonium sulphate solution required for blank titration; & T= Volume of ferrous ammonium sulphate needed for soil sample).

4.6.5 Estimation of Nitrogen (N) content

The procedure for the analysis of Nitrogen content in the soil samples was divided into three steps, viz. digestion, distillation and titration.

Digestion: 1gm of soil sample was taken in each of Kjeldahl flask for digestion tube and 10ml Conc. Sulphuric Acid was added in each flask. Also, 3gms of catalyst mixture (Kjeldahl catalyst) was added in each of digestion tube and the balance without a soil sample was maintained. Temperature was set at $420^{o}C$ and it was digested for approximately 1hr till the sample became green colour. Then, the digester was switched off and the flask was allowed to cool.

Distillation: Firstly, the conical flask was loaded (with 20ml of 40% Boric Acid) in the receiver side whch will be pink colour as it contain 3 drops of Bromo cresol green and Methyl red solution of 5 drops. Then, the digested sample was loaded for distillation. Again, 40% of NaOH was added slowly in automode in the order of 10ml each time till the colour changes from bluish green to brown precipitation and the process time was set for 6 minutes for soil sample. After 6 minutes, the sample colour in a conical flask changed fro pink to green to green colour which was the end point. The flask was then prepared for titration.

Titration: The distillated was titrated against 0.1N HCl. The titration was stopped when the colour changed from green to pake pink.

$$\% \text{ of Nitrogen} = \frac{14 \times \text{Titrant value} \times \text{Normality of acid} \times 100}{1000 \times \text{Sample wt.}}$$

4.6.6 Estimation of phosphorus

The methods developed by Olsen *et al.,* (1954) and Dickman & Brays (1940) was followed for the estimation of Phosphorus in the soil samples. 2.5g of the soil sample was taken in 100ml conical flask and a little of Dargo G 60 or equivalent grade of activated carbon (free of phosphorus) was added followed by 50ml of

Olsen's reagent. A blank is run without soil. Then the flask were shaken for 30 minutes on a platform type shaker and the contents are filtered immediately through dry filter paper (Whatman No. 1) into dry beakers or vials.

In the filtrate, phosphorus was estimated calorimetrically by Dickman and Bray's procedure (Dickman and Brays, 1940). 5ml of soil extract is pipette into a 25ml volumetric flask to which 5ml of the Dickman and Bray's reagent was poured in. The rock of the flask was washed down and the content was diluted to about 22ml. Therefore, 1ml of the diluted stannous chloride solution was added and the volume makes up to the mark level. The intensity of the blue colour was measured (using mµ filter) just after 10 minutes and the concentration of phosphorus was determined from the standard curve. With each sample a blank was maintained.

4.6.7 Estimation of Potassium

Available Potassium (K) incorporates both exchangeable and water soluble forms of the nutrient present in the soil. The estimation of K of water soluble forms was carried out with the help of Flame photometer as suggested by Ghost *et al.,* (1983). 5gms of soil sample was shaken with 25ml of normal of Ammonium acetate (pH 7) for 5 minutes and filtered immediately through a dry filter paper (Whatman No. 1). First few ml of the filtrate was rejected. Potassium concentration in the extract was determined in the flame photometer.

4.7 Biometrical observations

4.7.1 Growth parameters of maize

i) **Plant height (cm)**: Plant height were recorded in situ at 15, 30, 45 and 60 Days After Sowing (DAS) by randomly selecting 10 plants from each plot and heights were measured by linear scale from the ground level up to the flag leaf. The mean values were computed and expressed in cm.

ii) **Number of leaves per plant**: The number of leaves of 10 tagged plants from each plot were counted at different stages of 15, 30, 45 and 60 DAS and the mean number of leaves per plant were recorded.

iii) **Plant biomass (gm):** The plant aboveground biomass was harvested at plant maturity stage by cutting at the ground level. The plant material was cut into manageable size and kept in hot air oven at 70°C until constant weight of dryness was obtained. The dry plant material was then weighed using digital weighing balance and expressed in gram (gm).

4.7.2 Yield parameters of maize

i) **Number of cobs per plant**: The number of cob per plant was recorded from 10 plants which were randomly selected from each plot and the mean number of cob per plant were recorded.

ii) **Length of cobs**: Ten cobs per plot were randomly selected at the time of harvesting and the length of the cobs were measured and the mean cobs length were computed and expressed in cm.

iii) **Number of kernel’s row per cob**: From the randomly selected 10 cobs from each plot, the number of kernels row per cob were counted and the mean number of row were recorded.

iv) **Number of kernels per row**: The number of kernels in a row from randomly selected cobs from each plot were counted and the mean number were computed.

v) **Test weight (1000 grain weight)**: One thousand filled grains were counted from the grain sample and their weight were recorded in grams.

vi) **Grain yield**: The grain yield of maize for each treatment was calculated by using the formula,

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

viii) **Harvest Index**: The term “harvest index” is used to quantify the yield of a crop species versus the total amount of biomass that has been produced. The commercial yield can be grain, tuber or fruit. Harvest index can apply equally well to the ratio of yield to total plant biomass (shoots plus roots) but above-ground biomass is more common because root mass is so difficult to obtain. The harvest index of the maize for each treatment was calculated by using the formula,

$$\text{Harvest index \%} = \frac{\text{Economic yield (grains)}}{\text{Biological yield (Straw + grains}} \times 100$$

4.7.3 Statistical Analysis

The experimental data pertaining to each parameters were analyzed statistically. ANOVA was performed with the help of SigmaStat 4.0 software and Costat software.

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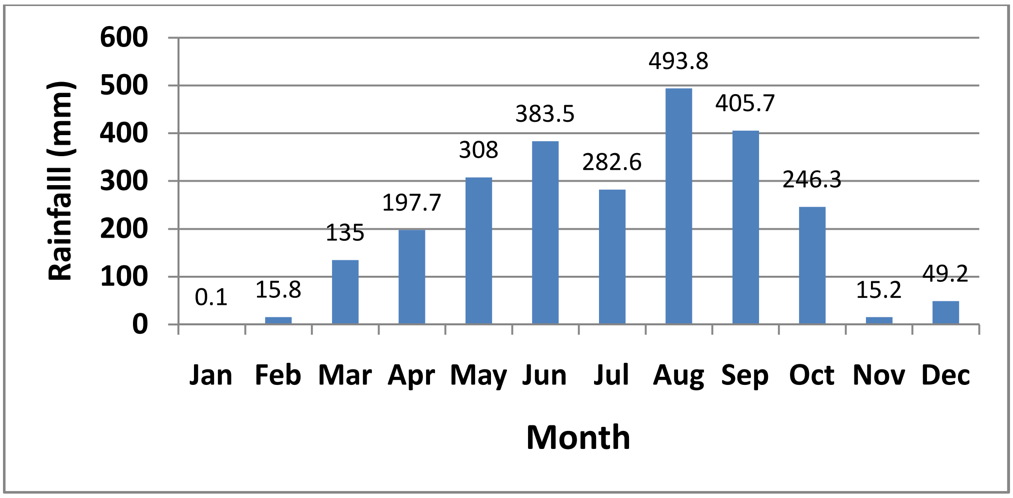
Chapter – V

Results

Table 5.1 Monthly rainfall of 2010 showing the rainfall pattern during the experimental period.



The rainfall pattern showed high rainfall during the experimental period from March to August, 2010. As maize is a water demanding crop, the experiment was conducted during the rainy seasons as *kharif* crop (Table 5.1). In Mizoram the slash and burning of forest vegetation occurred during the February and mid of March. Sowing of seeds is done mostly during end of March to May depending on the rainfall.

Table 5.2 Soil properties of 2JC, 3JC and 5JC before land preparation.

Jhum cycles	**pH**	**OC (%)**	**P_2O_5 (kg/ha)**	**K_2O (kg/ha)**	**Total N (%)**	**Soil texture**
2 JC	6.15	1.38	7.56	120	0.26	Sandy clay loam
3 JC	6.18	1.67	9.32	145	0.32	Sandy clay loam
5 JC	6.24	3.11	11.33	180	0.47	Sandy clay loam

5.2 Soil analysis

Soil properties of the three Jhum sites sampled before the land preparation for the experiment (Table 1) showed soil pH ranging from 6.15 in 2 years jhum to 6.24 in 5 years jhum. Similar trend with lowest values in 2 years jhum and highest 5 years jhum was also observed in other soil parameters ranging from 1.38 to 3.11 kg/ha in soil OC content, 7.56 to 11.33 kg/ha in available phosphate, 120 to 180 kg/ha in available potassium and 0.26 to 0.4 % in total nitrogen content (Table 5.2). Although slightly higher value in pH and higher content of OC, available phosphate, available potash and total nitrogen content occurred in longer jhum periods, all the soil in the three jhum cycles represent poor nutrient content for annual crop plantation.

5.3 Effect of Fertilizer application on growth performance

5.3.1 Plant height at 15 days after sowing:

As mentioned earlier, seeds were sown on 24th March, 2010 during which summer rain occurred. In response to the immediate rainfall after seed sowing, sprouting was observed from four days after sowing (DAS) of seeds. Measurement of plant height at 15 DAS showed significant variations among the fertilizer plots under each spacing treatment (Figure 5.3.1 & Table 5.3.1). Increased in plant height with increasing level of fertilizer application occurred in all the fertilizer plots of each spacing. In 2JC, minimum height of 13.85±0.46cm occurred in F0 plot of S1 spacing while maximum height of 18.38±0.28cm occurred in F3 plot of S3 spacing. In 3JC, in all the 3 spacing, minimum height ranging from 14.43±0.53cm to 15.14±0.47cm occurred in plots without fertilizer application where as maximum height ranging from 18.54±0.33 cm to 18.88±0.23cm occurred in plots with highest fertilizer application. In 5JC, the plant height of fertilizer plots under S2 spacing showed highest range of 14.77±0.34 cm (S2F0) to 19.11±0.19cm (S2F3).

5.3.2 Plant height at 30 DAS

Plant height at 30 DAS showed significant increase from F0 to F3 plots in S1 spacing in all the jhum cycles. Except in 2JC, the fertilizer plots under S2 and S3 spacing showed lesser variations in plant height. Comparatively lower plant height was observed among the different fertilizer plots under highest density spacing of S1 than that S2 and S3. The maximum height of 63.70±1.96cm (S1F3) in 3JC and 79.87±1.15cm (S1F3) in 5JC of the S1 spacing was comparable to the minimum values of 63.46±1.96 cm (S3F0) in 3JC and 81.30±3.01cm (S3F0) in 5JC of S3 spacing (Figure 5.3.2 & Table 5.3.2).

Unlike 15 DAS, the plant height in 30 DAS showed marked variations with high significant levels among the jhum cycles and the minimum values occurred in plots without fertilizer application under highest density spacing in S1F0 ranging from 43.16±1.95 cm in 2JC to 68.28±1.40cm in 5JC.

5.3.3 Plant height at 45 DAS

With the increase in growth duration, wider range in plant height among the fertilizer plots in each of the three spacing was observed. The high increase in plant height from the 30DAS to 45DAS indicated high growth rate of plants during 30 to 45 DAS, and comparative highly growth rate occurred in the fertilizer plots under S1 spacing. Statistically significant variations were observed among the fertilizer plots in under each of the three spacing (Figure 5.3.3 & Table 5.3.3). In 2JC, under the S1, S2 and S3 spacing, the minimum height to the maximum height ranged from 79.74±1.40 (S1F0) to 101.92±2.01cm (S1F3), 85.64±1.56 cm (S2F0) to 118.50±4.15 cm (S2F3) and, 83.55±3.36 cm (S3F0) to 122.42±6.62cm (S3F3) which accounted for 27.81%, 38.36%, 46.52%, increase in plant height respectively.

Significant response to fertilizer treatment was observed in 3JC ranging from 89.60±3.32cm (S1F0) to 121.09±5.11cm (S1F3) under S1 spacing, 97.83±2.92cm (S2F0) to 131.67±4.49cm (S2F3) under S2 spacing and, 106.73±2.98cm (S3F0) to 131.26±5.41cm (S3F3) under S3 spacing which accounted for the increase in 35.14%, 34.59%, 22.98% with fertilizer application in S1, S2 and S3 spacing respectively. In 5JC, less significant variation ranging from 142.34±3.56cm (S1F0) to 170.67±4.33 cm (S1F3) was observed in S1 spacing while higher significant difference ranging from 159.81±3.50 cm (S2F0) to 184.26±3.14cm (S2F3) in S2 spacing and, 153.94±2.40cm (S3F0) to 181.31±3.44cm (S3F3) in S3 Spacing was recorded which accounted for 19.90%, 15.29%, 17.77% increase from the minimum height.

The inter jhum comparison of each fertilizer plots showed highly significant difference ($P<0.001$). In plot without fertilizer application (F0), the increase in plant height from 2JC to 5JC ranged from 79.74±1.40cm to 142.34cm in S1, 85.64±1.56 cm to 159.81±3.50 cm in S2 and, 83.55±3.36cm to 153.94±2.40cm in S3.

5.3.4 Plant height at 60DAS

The height measurement at 60DAS showed high growth rate between 45 and 60DAS in 2JC and 3JC where around 100% increase in plant was observed. In 2JC, the significant difference in height ranged from 162.23±4.12cm (S1F0) to 184.63±5.14cm (S1F3) in S1 spacing; 185.61±3.38cm (S2F0) to 215.34±2.49cm (S2F3) in S2 spacing and, 188.32±1.48cm (S3F0) to 212.72±3.29cm (S3F3) in S3 spacing which accounted for %%% increase in height from their respective minimum height. 3JC also showed similar trend with minimum and maximum plant height ranging from 165.38±2.10cm in (S1F0) to 212.54±1.36cm (S1F3) in S1 spacing, 190.51±5.36cm (S2F0) to 218.72±1.00cm (S2F3) in S2 spacing and, 193.98±2.55cm (S3F0) to 217.52±2.60cm (S3F3) in S3 spacing (Figure 5.3.4 & Table 5.3.4).

Slower growth rate was observed in 5JC during 45 to 60DAS when compared with that of 30 to 45DAS period. 5JC also showed similar trend to that of 2JC and 3JC with lowest plant height among fertilizer plots under S1 spacing when compared with that of S2 and S3. The minimum to maximum plant height ranged from 182.33±3.84cm (S1F0) to 212.54±1.36cm (S1F3) in S1 spacing, 205.52±2.04cm (S2F0) to 229.92±0.28cm (S2F3) in S3 spacing and, 206.89±1.42cm (S3F0) to 232.63±1.36cm (S3F3) in S3 spacing which accounted for 16.56%, 11.87%, 12.44% increase in plant height from the minimum plant height.

Despite of the highly significant difference at 45DAS with high value in 5JC, the plant height at 60DAS showed lower range with less significant variations among the three jhum cycles. Similar trend of lowest plant height in 2JC followed by 3JC and highest in 5JC was also observed at 60DAS. The inter jhum comparison of plant height showed highest increase in

5.3.5 Number of leaves at 15 DAS

Although similar pattern with that of plant height of increasing values with increasing in fertilizer application was observed in the number of leaves per plant at 15DAS, there was almost no significant difference among the different fertilizer plots under different spacing in the three jhum cycles. Number of leaves showed narrow range among the four fertilizer treatments (F0, F1, F2 and F3) under different spacing (Figure 5.3.5 & Table 5.3.5).

Comparable values in number of leaves per plant was observed among the different fertilizer treatments of 2JC, 3JC and 5JC. Except in S1F0, there was no significant difference in number of leaves among the jhum cycles.

5.3.6 Number of leaves per plant at 30DAS

In comparison with the record of 15 DAS, higher significant level was observed among the fertilizer treatment plots of S1, S2 and S3 spacing. Plants grown without fertilizer application contain lower number of leaves per plant in all the three spacing in 2JC, 3JC and 5JC. Plants under highest density (S1) showed lowest number of leaves ranging from 7.08±0.11 (S1F0) to 7.68±0.08 (S1F3) in 2JC; 7.57±0.02 (S1F0) to 7.92±0.10 (S1F3) in 3JC and, 7.71±0.09 (S1F0) to 8.02±0.08 (S1F3) in 5JC (Figure 5.3.6 & Table 5.3.6).

Among the jhum cycles, lowest number of leaves occurred in 2JC followed by 3JC and highest in 5JC. Statistically significant ($P<0.05$) difference was observed among the three jhum cycles in F0 and F1 fertilizer plots under the S1, S2 and S3 spacings.

5.3.7 Number of leaves per plant at 45DAS

At 45DAS, higher significant difference was observed among the fertilizer treatment plots in S1, S2 and S3 spacings except in 2JC. The increase in number of leaves per plant was higher during 30 to 45 DAS when compared with the period of 15 to 30 DAS (Figure 5.3.7 & Table 5.3.7). The minimum and maximum number of leaves per plant ranged from 9.85±0.31 (S1F0) to 10.87±0.20 (S1F3) in S1 spacing, 10.98±0.25 (S2F0) to 11.59±0.17 (S2F3) in S2 spacing and, 11.13±0.15 (S3F0) to 11.63±0.14 (S3F2)in S3 spacing in 2JC. The fertilizer treatment plots of 3JC showed higher number of leaves per plant than 2JC and the minimum and maximum value ranged from 11.35±0.04 (S1F0) to 11.79±0.03 (F1S3) in S1 spacing, 11.40±0.03 (S2F0) to 11.80±0.09 (S2F3) in S2 spacing and, 11.45±0.06 (S3F0) to 11.81±0.09 (S3F3) in S3 spacing. Plant of 5JC showed highest number of leaves in each fertilizer treatment plots ranging from 11.79±0.04 (S1F0) to 12.22±0.02 (S1F3) in S1, 11.84±0.01 (S2F0) to 12.25±0.03 (S2F3) and, 11.82±0.05 (S3F0) to 12.21±0.04 (S3F3) in S3 spacing.

5.3.8 Number of leaves per plant at 60DAS

In 2JC, significant difference in number of leaves per plant ranging from 10.59±0.17 (S1F0) to 11.50±0.09 (S1F3) in S1 spacing, 11.98±0.05 (S2F0) to 12.56±0.02 (S2F3) in S2 spacing and, 12.09±0.06 (S3F0) to 12.55±0.06 (S3F3) in S3 spacing which accounted for 8.50%, 4.48% and 3.80% increase from the minimum value respectively (Figure 5.3.8 & Table 5.3.8). Surprisingly reduction in number of leaves per plant from that of 45DAS was observed in most of the fertilizer plots in S1 of 3JC and 5JC. In 3JC, the minimum and maximum values ranged from 10.49±0.36 (S1F0) to 11.17±0.05 (S1F3) in S1, 12.06±0.15 (S2F0) to 12.78±0.34 (S2F3) in S2 spacing and, 12.18±0.11 (S3F0) to 12.99±0.25 (S3F3) in S3 spacing which accounted for 6.48%, 5.97%, 6.65% increase from the minimum values. In 5JC, the minimum and maximum values ranged from 10.87±0.34 (S1F0) to 12.34±0.14 (S1F3) in S1 spacing, 12.48±0.28 (S2F0) to 13.68±0.07 (S2F3) in S2 cycle and, 12.27±0.54 (S3F0) to 13.66±0.05 (S3F3) in S3 spacing which accounted for increase in 13.52%, 9.61%, 11.32% for the minimum values respectively.

5.3.9 Biomass at harvest

Ten plants per replication was harvested at maturity stage at 23rd & 24th July, 2010 for the determination of biomass. The plant dry biomass at maturity harvest showed significant variations among the different fertilizer plots of S1, S2 and S3 spacing. Among three spacing, the fertilizer plots of S1 spacing showed much lesser plant biomass ranging from 264.50±17.37gm (S1F0) to 319.50± 13.12 gm (S1F3) in S1 spacing, 318.50±14.40 gm (S2F0) to 371.50±6.08 gm (S2F3) in S2 spacing and, 316.50±3.97 gm (S3F0) to 374.20±4.09 gm (S3F3) in S3 spacing. Slight increase in dry biomass per plant from 2JC was observed in 3JC (except S2F0) with minimum to maximum plant biomass ranging from 267.77±4.91 gm (S1F0) to 322.38±6.39 gm (S1F3) in S1 spacing, 308.55±3.87 gm (S2F0) to 376.03±5.67 gm (S2F3) in S2 spacing and, 319.66±3.01 gm (S3F0) to 377.08±2.28 gm (S3F3) in S3 spacing. Highest dry biomass per plant was observed in 5JC which ranged from 292.60±4.50 gm (S1F0) to 327.13±5.96 gm (S1F3) in S1 spacing, 335.80±2.75 gm (S2F0) to 386.11±1.79 gm (S2F3) in S2 spacing and, 337.72±2.78 gm (S3F0) to 390.93±4.39 gm (S3F3) in S3 spacing (Figure 5.3.9 & Table 5.3.9).

The percentage increase in plant biomass from the plot without fertilizer application to the highest fertilizer application in S1, S2 and S3 spacing were 20.79%, 16.64% and 18.23%, in 2JC, 20.40%, 21.87% and 17.96% in 3JC and, 11.80%, 14.98% and 15.75% in 5JC.

Among the jhum cycle, lowest biomass production occurred in 2JC follow by 3JC and highest in 5JC. Low level of significant difference was observed in each fertilizer plots of S1 spacing. In S2 spacing, significant difference among jhum cycles was observed in S2F1 and S2F3. Each fertilizer plots of S3 spacing showed significant difference ($P<0.05$ to $P>0.001$). From the all the fertilizer treatments of the three jhum cycles, the lowest biomass per plant of 264.50±7.37gm (S1F0) of 2JC to 390.93±4.29gm (S3F3) of 5JC accounted for 47.79% increased in plant biomass.

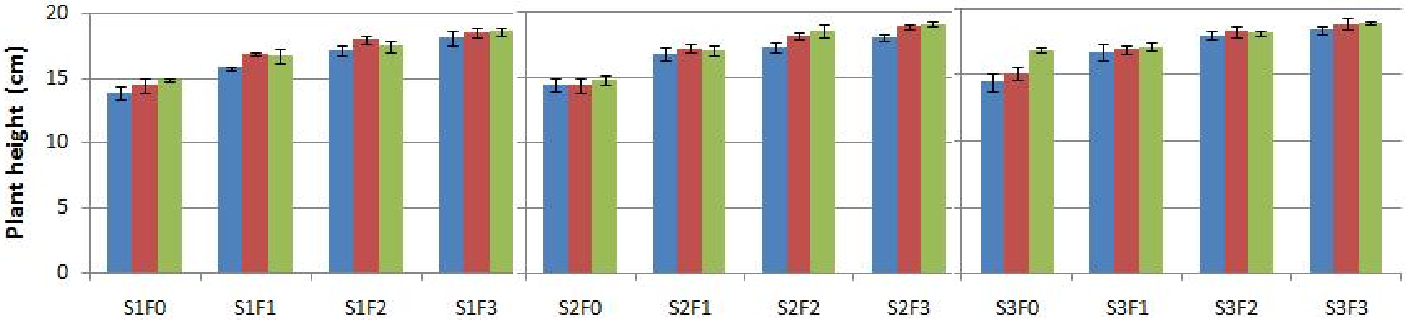


Figure 5.3.1 Effect of fertilizer application on plant height at 15 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

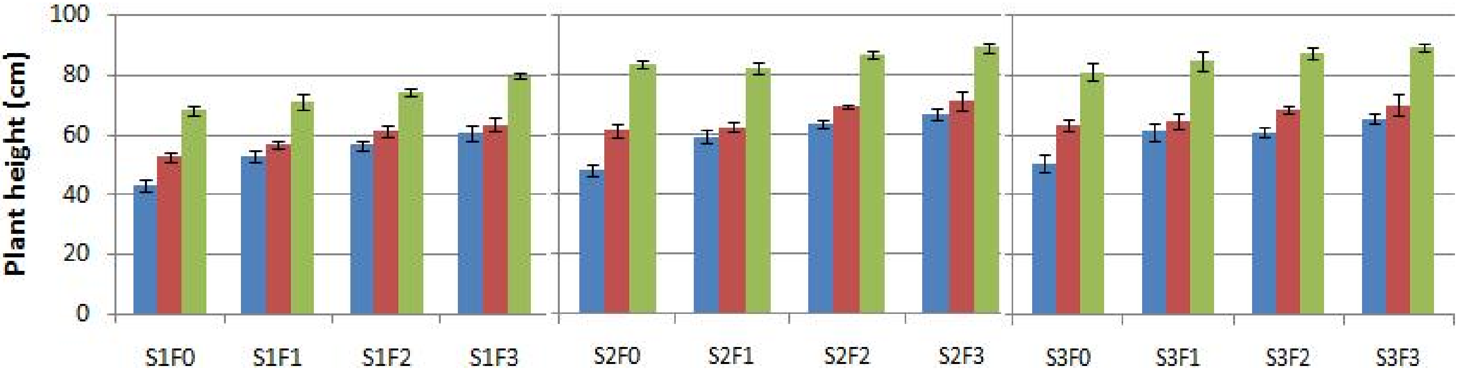


Figure 5.3.2 Effect of fertilizer application on plant height at 30 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table5.3.1: Plant height at 15 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	13.85 ±0.46	15.80 ±0.11	17.16 ±0.36	18.13 ±0.55	*** 1.26	14.42 ±0.48	16.78 ±0.47	17.30 ±0.34	18.10 ±0.23	** 2.35	14.47 ±0.67	16.69 ±0.59	17.96 ±0.29	18.38 ±0.28	** 1.69
3JC	14.43 ±0.53	16.91 ±0.16	17.98 ±0.34	18.54 ±0.33	*** 1.63	14.37 ±0.61	17.19 ±0.31	18.19 ±0.29	18.88 ±0.23	*** 3.03	15.14 ±0.47	16.90 ±0.34	18.26 ±0.46	18.86 ±0.44	** 1.76
5JC	14.90 ±0.11	16.72 ±0.54	17.44 ±0.42	18.62 ±0.29	*** 1.82	14.77 ±0.34	17.06 ±0.40	18.52 ±0.51	19.11 ±0.19	*** 1.45	16.86 ±0.17	17.11 ±0.33	18.13 ±0.13	18.96 ±0.13	*** 0.83
LSD (0.05)	ns	ns	ns	ns		ns	ns	Ns	* 0.78		* 1.72	ns	ns	ns	

* = P<0.05, ** = P<0.01, *** = P<0.001

Table5.3.2: Plant height at 30 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	43.16 ±1.95	52.88 ±1.96	56.60 ±1.70	60.66 ±2.71	** 7.77	48.18 ±1.90	59.57 ±2.32	63.62 ±1.34	66.94 ±1.81	*** 7.37	50.87 ±2.94	61.59 ±2.94	61.30 ±1.66	65.69 ±1.73	* 10.71
3JC	52.72 ±1.57	56.83 ±1.36	61.27 ±1.87	63.70 ±1.96	** 6.87	61.76 ±2.21	62.53 ±1.60	69.63 ±0.51	71.41 ±3.18	* 2.37	63.46 ±1.96	64.90 ±2.43	68.67 ±1.24	70.44 ±3.39	ns
5JC	68.28 ±1.40	71.14 ±2.70	74.67 ±1.38	79.87 ±1.15	** 6.33	83.79 ±1.54	82.32 ±2.09	87.18 ±1.35	89.38 ±1.57	ns	81.30 ±3.01	84.83 ±3.27	87.69 ±1.83	89.56 ±1.57	ns
LSD (0.05)	*** 9.56	** 14.31	*** 13.4	** 16.16		*** 13.57	*** 19.78	*** 6.01	** 17.97		*** 12.59	** 19.92	*** 7.36	*** 19.12	

* = P<0.05, ** = P<0.01, *** = P<0.001.

Figure 5.3.3 Effect of fertilizer application on plant height at 45 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Figure 5.3.4 Effect of fertilizer application on plant height at 60DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.3.3 : Plant height at 45 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	79.74 ±1.40	89.46 ±1.88	97.52 ±5.89	101.92 ±2.01	** 12.46	85.64 ±1.56	100.03 ±3.37	112.10 ±4.15	118.50 ±4.15	*** 12.06	83.55 ±3.36	98.28 ±2.67	115.34 ±3.51	122.42 ±6.62	*** 14.72
3JC	89.60 ±3.32	101.63 ±1.61	109.35 ±1.43	121.09 ±5.11	*** 11.73	97.83 ±2.92	103.21 ±2.47	118.93 ±5.17	131.67 ±4.49	** 15.72	106.73 ±2.98	111.11 ±3.35	122.84 ±2.54	131.26 ±5.41	** 16.11
5JC	142.34 ±3.56	157.08 ±5.69	163.85 ±3.57	170.67 ±4.33	* 14.74	159.81 ±3.50	166.56 ±2.89	171.34 ±4.21	184.26 ±3.14	** 11.53	153.94 ±2.40	168.37 ±4.06	175.33 ±3.48	181.31 ±3.44	** 12.94
LSD (0.05)	*** 52.74	*** 55.44	*** 54.49	*** 19.16		*** 12.18	*** 63.35	*** 52.4	*** 52.58		*** 23.18	*** 12.83	*** 52.49	*** 50.05	

* = P<0.05, ** = P<0.01, *** = P<0.001.

Table 5.3.4: Plant height at 60 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	162.23 ±4.12	169.03 ±3.84	177.50 ±5.02	184.63 ±5.14	* 15.26	185.61 ±3.38	195.74 ±3.36	207.87 ±2.62	215.34 ±2.49	*** 10.13	188.32 ±1.48	197.45 ±4.72	206.25 ±1.92	212.72 ±3.29	** 15.26
3JC	165.38 ±2.10	177.44 ±5.60	186.50 ±4.55	196.14 ±5.32	** 18.7	190.51 ±5.36	200.58 ±1.64	210.98 ±2.39	218.72 ±1.00	*** 10.40	193.98 ±2.55	202.05 ±2.01	209.45 ±4.19	217.52 ±2.60	** 15.47
5JC	183.33 ±3.84	194.88 ±3.47	201.41 ±4.70	212.54 ±1.36	** 17.66	205.52 ±2.04	212.32 ±2.92	217.45 ±2.10	229.92 ±0.28	*** 6.80	206.89 ±1.42	211.03 ±1.84	217.83 ±2.27	232.63 ±1.36	*** 6.80
LSD (0.05)	** 17.95	* 17.43	* 23.91	* 16.39		* 15	* 11.73	ns	** 11.2		** 12.91	ns	ns	** 15.11	

* = P<0.05, ** = P<0.01, *** = P<0.001.

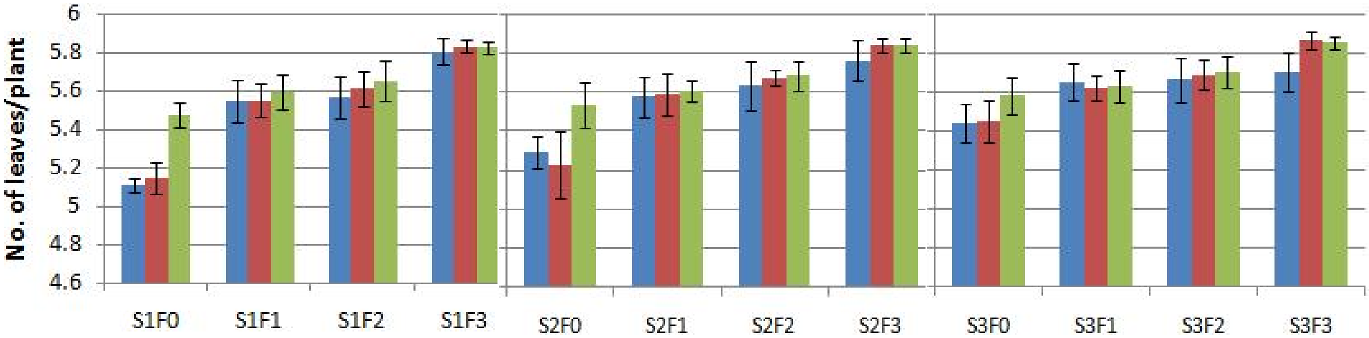


Figure 5.3.5 Effect of fertilizer application on number of leaves per plant at 15 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

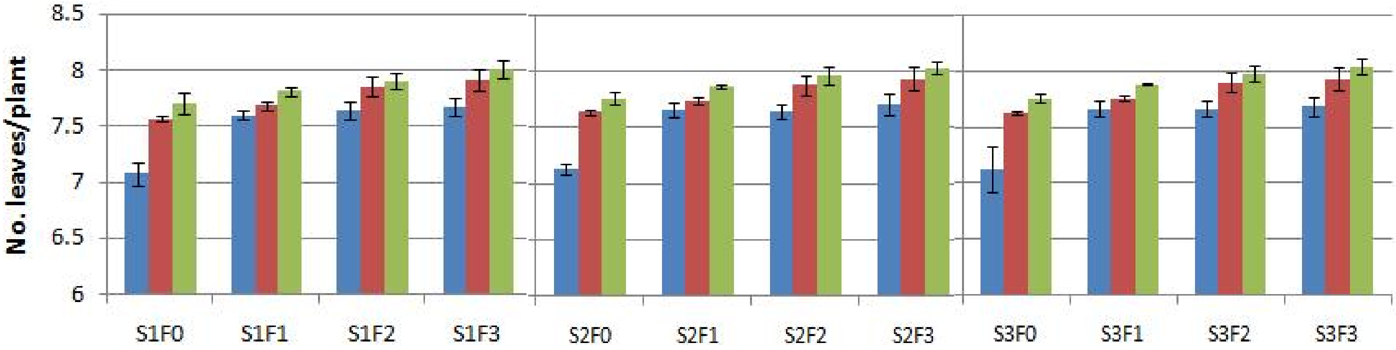


Figure 5.3.6 Effect of fertilizer application on plant height at 30 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.3.5 : No. of Leaves at 15 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	5.11 ±0.03	5.54 ±0.10	5.56 ±0.111	5.80 ±0.06	** 0.43	5.29 ±0.08	5.58 ±0.10	5.63 ±0.12	5.76 ±0.10	NS	5.44 ±0.10	5.65 ±0.09	5.66 ±0.11	5.70 ±0.10	NS
3JC	5.15 ±0.08	5.55 ±0.086	5.61 ±0.09	5.83 ±0.034	** 0.28	5.23 ±0.16	5.59 ±0.10	5.67 ±0.04	5.84 ±0.03	* 2.45	5.45 ±0.10	5.62 ±0.06	5.69 ±0.07	5.86 ±0.04	* 0.41
5JC	5.47 ±0.06	5.59 ±0.09	5.65 ±0.10	5.82 ±0.034	NS	5.53 ±0.11	5.61 ±0.05	5.68 ±0.07	5.84 ±0.03	NS	5.58 ±0.09	5.63 ±0.08	5.70 ±0.07	5.85 ±0.02	NS
LSD (0.05)	* 0.32	ns	ns	ns		ns	ns	ns	ns		ns	ns	ns	ns	

* = P<0.05, ** = P<0.01, *** = P<0.001.

Table 5.3.6: No. of Leaves at 30 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	7.08 ±0.11	7.60 ±0.04	7.65 ±0.08	7.68 ±0.08	** 0.52	7.13 ±0.04	7.65 ±0.06	7.64 ±0.07	7.71 ±0.10	** 0.51	7.14 ±0.20	7.67 ±0.07	7.67 ±0.08	7.69 ±0.08	* 0.53
3JC	7.57 ±0.02	7.69 ±0.04	7.86 ±0.09	7.92 ±0.10	* 0.29	7.64 ±0.02	7.74 ±0.03	7.88 ±0.09	7.94 ±0.10	ns	7.63 ±0.02	7.77 ±0.03	7.90 ±0.09	7.94 ±0.10	ns
5JC	7.71 ±0.09	7.82 ±0.04	7.91 ±0.07	8.02 ±0.08	ns	7.76 ±0.06	7.87 ±0.02	7.96 ±0.07	8.03 ±0.06	* 0.20	7.77 ±0.05	7.89 ±0.00	7.99 ±0.07	8.05 ±0.08	* 0.21
LSD (0.05)	** 0.48	* 0.21	ns	ns		*** 0.5	* 0.21	ns	ns		* 0.49	* 0.22	ns	ns	

* = P<0.05, ** = P<0.01, *** = P<0.001.

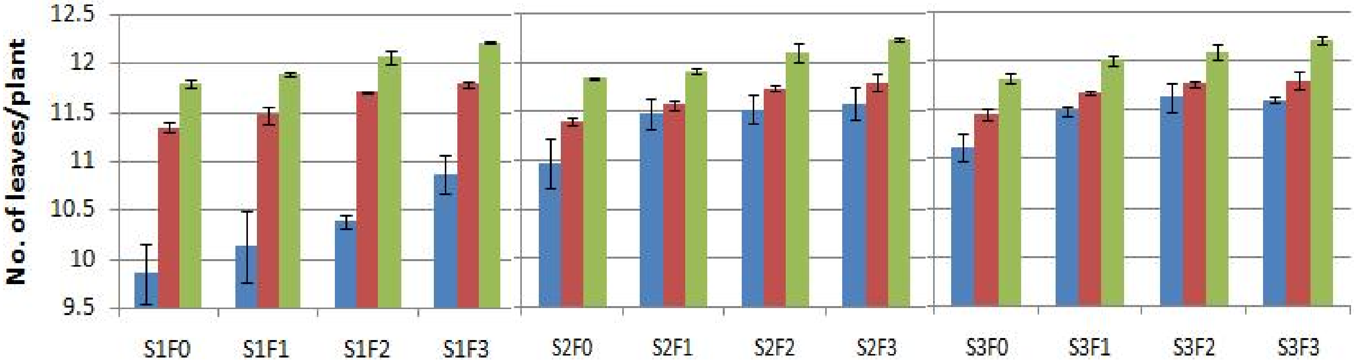


Figure 5.3.7 Effect of fertilizer application on number of leaves per plant at 45 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

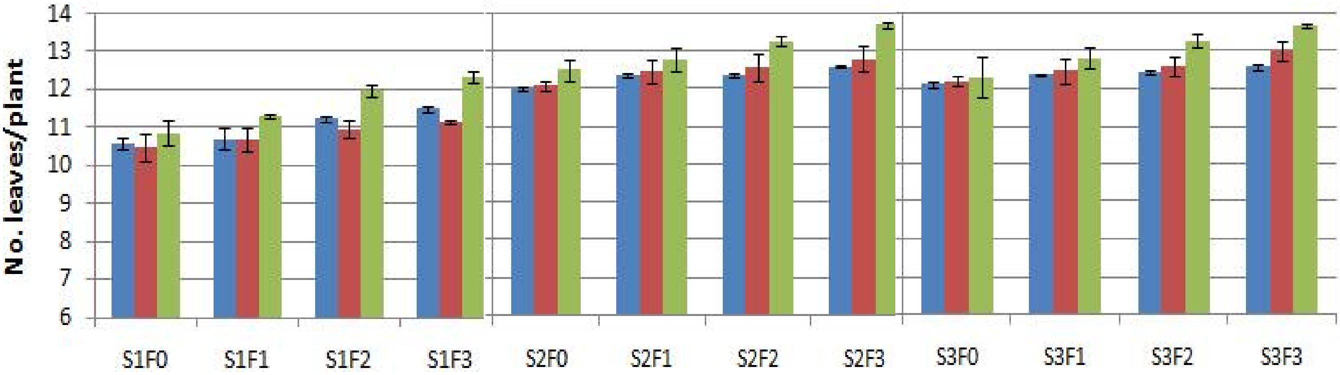


Figure 5.3.8 Effect of fertilizer application on number of leaves per plant at 60 DAS under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.3.7: No. of Leaves at 45 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	9.85 ±0.31	10.13 ±0.36	10.39 ±0.07	10.87 ±0.20	ns	10.98 ±0.25	11.48 ±0.15	11.53 ±0.14	11.59 ±0.17	ns	11.13 ±0.15	11.50 ±0.05	11.63 ±0.14	11.61 ±0.03	* 0.37
3JC	11.35 ±0.04	11.48 ±0.09	11.71 ±0.01	11.79 ±0.03	** 0.23	11.40 ±0.03	11.57 ±0.05	11.74 ±0.02	11.80 ±0.09	** 0.22	11.45 ±0.06	11.68 ±0.01	11.78 ±0.03	11.81 ±0.09	* 0.22
5JC	11.79 ±0.04	11.89 ±0.02	12.06 ±0.07	12.22 ±0.02	*** 0.15	11.84 ±0.01	11.92 ±0.02	12.10 ±0.10	12.25 ±0.03	** 0.18	11.83 ±0.05	12.01 ±0.06	12.11 ±0.08	12.21 ±0.04	** 0.20
LSD (0.05)	*** 1.49	** 1.34	*** 0.35	*** 0.42		* 0.86	* 0.34	* 0.36	* 0.44		** 0.37	*** 0.18	* 0.47	** 0.4	

* = P<0.05, ** = P<0.01, *** = P<0.001.

Table 5.3.8: No. of Leaves at 60 days after sowing (DAS) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	10.59 ±0.17	10.71 ±0.28	11.25 ±0.07	11.50 ±0.09	* 0.65	11.98 ±0.05	12.35 ±0.05	12.34 ±0.06	12.56 ±0.02	*** 0.21	12.09 ±0.06	12.34 ±0.02	12.41 ±0.04	12.55 ±0.06	** 0.21
3JC	10.49 ±0.36	10.69 ±0.32	10.97 ±0.24	11.17 ±0.05	ns	12.06 ±0.15	12.44 ±0.30	12.54 ±0.37	12.78 ±0.34	ns	12.18 ±0.11	12.45 ±0.33	12.58 ±0.27	12.99 ±0.25	ns
5JC	10.87 ±0.34	11.32 ±0.07	11.98 ±0.17	12.34 ±0.14	** 1.02	12.48 ±0.28	12.75 ±0.31	13.24 ±0.15	13.68 ±0.07	* 0.76	12.27 ±0.54	12.80 ±0.30	13.25 ±0.18	13.66 ±0.05	ns
LSD (0.05)	ns	ns	* 0.73	*** 0.84		ns	ns	ns	* 0.9		ns	ns	* 0.67	** 0.67	

* = P<0.05, ** = P<0.01, *** = P<0.001

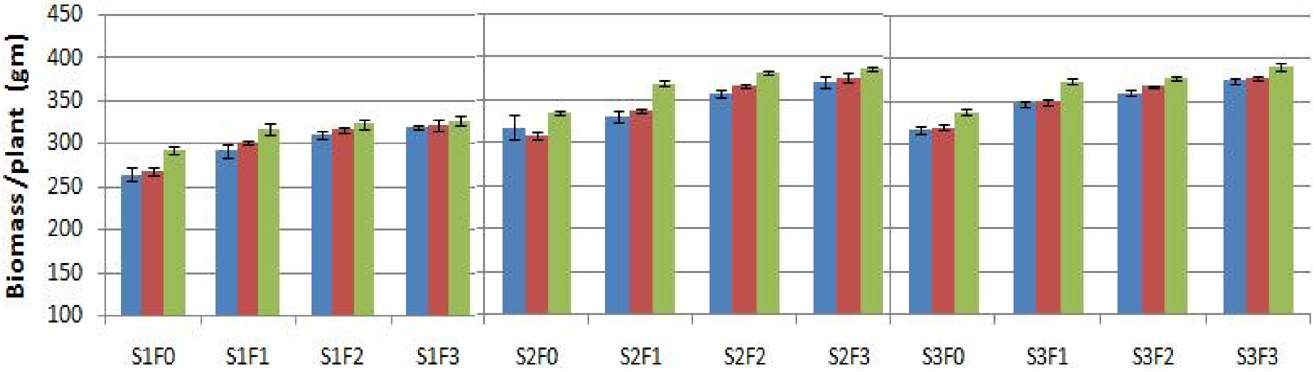


Figure 5.3.9 Effect of fertilizer application on number biomass production at maturity harvest under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.3.9: Biomass at maturity harvest under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	162.23 ±4.12	169.03 ±3.84	177.50 ±5.02	184.63 ±5.14	* 15.26	185.61 ±3.38	195.74 ±3.36	207.87 ±2.62	215.34 ±2.49	*** 10.13	188.32 ±1.48	197.45 ±4.72	206.25 ±1.92	212.72 ±3.29	** 15.26
3JC	165.38 ±2.10	177.44 ±5.60	186.50 ±4.55	196.14 ±5.32	** 18.7	190.51 ±5.36	200.58 ±1.64	210.98 ±2.39	218.72 ±1.00	*** 10.40	193.98 ±2.55	202.05 ±2.01	209.45 ±4.19	217.52 ±2.60	** 15.47
5JC	183.33 ±3.84	194.88 ±3.47	201.41 ±4.70	212.54 ±1.36	** 17.66	205.52 ±2.04	212.32 ±2.92	217.45 ±2.10	229.92 ±0.28	*** 6.80	206.89 ±1.42	211.03 ±1.84	217.83 ±2.27	232.63 ±1.36	*** 6.80
LSD (0.05)	** 17.95	* 17.43	* 23.91	* 16.39		* 15	* 11.73	ns	** 11.2		** 12.91	ns	ns	** 15.11	

* = P<0.05, ** = P<0.01, *** = P<0.001

5.4 Effect of fertilizer application on yield parameters

10 plants per replication plot was harvested on 23rd&24th July, 2010 for the determination of yield parameters Number of cobs per plant was counted and all the plants irrespective of difference levels of fertilizer application and jhum cycles produce only one harvestable cob, and the second cob, if produced, was under-developed and had no commercial value. So, only the first cob was considered in the yield parameters.

5.4.1 Length of Cob

The plants grown under different fertilizer treatment showed marked significant difference in S1, S2 and S3 spacing of 2JC and 3JC where as in 5JC, significant difference was observed only in fertilizer plots under S1 spacing. In 2JC, the minimum value was observed in F0 plot in S1, S2 and S3 spacing ranging from 14.70±0.17 cm (S1) to 17.50 cm (S3), and the maximum value in F3 plots ranged from 17.31±0.14 cm (S1) to 19.10±0.31 cm (S3) (Figure 5.4.1 & Table 5.4.1). In 3JC, the minimum values among S1, S2 and S3 ranged from 16.00±0.40 cm (S1F0) to 18.94±0.18 cm (S2F0) and the maximum values ranged from 18.87±0.18 cm (S1F3) to 20.62±0.23 cm (S2F3). 5JC showed highest LoC with minimum values of 17.73±0.38 cm (S1F0), 20.66±0.12 cm (S2F0) and 20.65±0.16 cm (S3F0), and maximum values of 20.16±0.18 cm (S1F0), 22.08±0.31 cm (S2F3) and 22.08±0.39 cm (S3F3).

Highly significant ($P<0.01$) difference was observed in each fertilizer treatment plots among the jhum cycles. In S1 spacing, the maximum value of 17.31±0.14 cm (S1F2) in 2JC was comparable with the minimum value of 17.73±0.38 cm (S1F0) in 5JC. Likewise, the maximum value in LoC under high fertilizer application plots of S2 and S3 of 2JC was comparable and slightly lower than the corresponding minimum values of 5JC.

5.4.2 Kernel row per cob

Although increasing in kernel rows per cob with increasing fertilizer application was observed in S1, S2 and S3 spacings, statistically significant difference among the fertilizer treatment plots was observed only in S1 and S2 spacings of 2JC (Figure 5.4.2 & Table 5.4.2). The maximum Kernel row per cob of 11.05±0.23 of 2JC, 11.45±0.12 of 3JC and 11.99±0.11 of 5JC in S1 spacing was lower than minimum values of 11.61±0.22 (S2) and 11.74±0.18 (S3) of 2JC, 11.99±0.08 (S2) and 12.19±0.15 (S3) of 3JC and, 12.63±0.09 (S2) and 12.71 (S3) of 5JC respectively.

Among the three jhum cycles, the difference in kernel row per cob was statistically significant ($P<0.05$) in each of the fertilizer treatments with lowest number in 2JC and increasing with longer jhum cycles.

5.4.3 Number of kernels per row

The number of kernels per row showed statistically significant ($P<0.05$) different among the plants grown under different levels of fertilizer application in all the three jhum cycles except in S2 spacing of 2JC. Evidently lower number of kernels in each kernel row was observed in the fertilizer plots of S1 spacing when compared with their corresponding plots in S2 and S3 spacings in all the three jhum cycles (Figure 5.4.3 &Table 5.4.3). Similar to the kernel row per cob, the maximum number of kernels per row of 27.75±0.18 in 2JC, 30.90±0.10 in 3JC and 32.90±0.29 in 5JC was lower than that of the minimum values of S2 spacing (31.63±0.17, 35.01±0.33 and 36.67±0.19 in 2JC, 3JC and 5JC respectively) and S3 spacing (31.42±0.10, 34.51±0.11 and 36.70±0.38 in 2JC, 3JC and 5JC respectively).

The minimum and maximum values among all the fertilizer and spacing treatment plots ranged from 26.24±0.48 (S1F0) to 33.44±0.34 (S3F3) in 2JC, 28.96±0.34 (S1F0) to 36.11±0.14 (S2F3) in 3JC and, 31.63±0.19 (S1F1) to 38.58±0.22 (S2F3) in 5JC.

The number of kernels per row among each fertilizer treatment plots showed highly significant ($P<0.001$) variations of lowest values in 2JC and highest values in 5JC. In S1 spacing, the number of kernels per row ranged between 26.24±0.48 to 27.75±0.18 in 2JC, 28.96±0.34 to 30.90±0.10 in 3JC and 31.63±0.19 to 32.90±0.29 in 5JC. Fertilizer plots in S2 and S3 spacings showed comparable values ranging from ca. 31 to 33 in 2JC, 34 to 36 in 3JC and 36 to 38 in 5JC.

5.4.4 Number of kernels per cob

Similar to the previous yield parameters of kernel rows per cob and number of kernels per row, the number of kernels per cob showed marked difference among the fertilizer plots as well as among the different spacing. Fertilizer plots of 2JC showed highly significant difference ranging from 270.44±7.03 (S1F0) to 306.59±6.78 (S1F3) in S1 spacing, 368.47±3.82 (S2F0) to 410.65±3.14 (S2F3) in S2 spacing and, 368.99±5.35 (S3F0) to 417.93±2.61 (S3F3) in S3 spacing (Figure 5.4.4 & Table 5.4.4). 3JC also showed similar trend ranging from 317.57±14.90 (S1F0) to 353.72±4.86 (S1F3) in S1 spacing, 414.76±3.48 (S2F0) to 460.25±4.50 (S2F3) in S2 spacing and, 420.62±6.33 (S2F0) to 456.77±5.34 (S3F3) in S3 spacing. 5JC showed highest number of kernels per cob in each fertilizer treatment ranging from 373.21±4.22 (S1F0) to 394.36±4.96 (S1F3) in S1 spacing, 462.95±1.90 (S2F0) to 506.11±5.16 (S2F3) in S2 spacing and, 469.83±2.47 (S3F0) to 508.71±0.72 (S3F3) in

S3 spacing. The maximum values of kernels per cob in each of the jhum cycles were lower than the minimum values of the fertilizer plots of S2 and S3 spacings.

The number of kernels per cob in each fertilizer treatments showed highly significant variations (P<0.001) with lowest values in 2JC followed by 3JC and highest in 5JC. The increase in number of kernels per cob from 2JC to 5JC in each fertilizer plot ranged from ca. 70 to 100.

5.4.5 Test weight

Test weight, that is the weight of randomly selected 1000 seeds showed significant variations (P<0.05) among the fertilizer plots in all the three jhum cycles (Figure 5.4.5 & Table 5.4.5). In 2JC, the test weight ranged from 255.33±2.60 gm(S1F0) to 275.67±2.40 gm (S1F3) in S1 spacing, 275.33±3.18 gm (S1F0) to 303.00±1.16 gm (S2F3) in S2 spacing and, 277.00±2.08 gm (S3F0) to 303.28±1.36 gm (S3F3) in S3 spacing. In 3JC, the minimum and maximum values of the fertilizer plots ranged from 263.67±1.86 gm (S1F0) to 281.67±1.45 gm (S1F3) in S1 spacing, 283.67±1.86 gm (S2F0) to 305.33±0.88 gm (S2F3) in S2 spacing and, 284.67±1.45 gm (S3F0) to 306.00±0.58 gm (S3F3) in S3 spacing. Lower significant variations was observed among the fertilizer plots of S1, S2 and S3 spacing ranging from 274.20±1.73 gm (S1F0) to 288.73±0.37 gm (S1F3) in S1 spacing, 293.50±3.67 gm (S2F0) to 309.24±1.92 gm (S2F3) in S2 spacing and, 293.33±2.19 gm (S3F0) to 311.08±1.45 gm (S3F3) in S3 spacing. The increase in test weight from the lowest weight to the highest weight among the fertilizer plots of S1, S2 and S3 accounted for 7.96%, 10.05% and 9.49% increase in 2JC, 6.83%, 7.64% and 7.49% in 3JC and 5.30%, 5.36% and 6.05% increase in 5JC respectively. The maximum test weight of

S1F3 plots in S1 was comparable with the lowest weight of the plots without fertilizer input (F0) in S2 and S3.

The test weight in each fertilizer plots among the jhum cycles showed significant variations S1F0, S1F1, S1F3, S2F0, S2F2, S3F0, S3F2 and S3F3. Test weight increases from 2JC with increase in the period of jhum cycle.

5.4.6 Grain yield

The grain yield in terms of dry weight showed highly significant (P<0.01) difference among most of the fertilizer treatments. Comparatively lower grain yield was observed among the fertilizer plots in S1 spacing. Grain yield increased with increase in fertilizer application as well as increase in the period of jhum cycle (Figure 5.4.6 & Table 5.4.6). The range of the minimum to the maximum grain yield in 2JC was 6274.4±105.11 kg (S1F0) to 7683.5±188.8 kg (S1F3) in S1 spacing, 6764.2±127.26 kg (S2F0) to 8294.7±46.24 kg (S2F3) in S2 spacing and, 6812.9±77.69 kg (S3F0) to 8449.9±64.56 kg (S3F3) in S3 spacing which accounted for 22.46%, 22.63% and 24.03% increase in grain yield. In 3JC, grain yield ranged from 7614.7±388.7 kg (S1F0) to 9057.8±145.10 kg (S1F3) in S1 spacing, 7842.8±38.07 kg (S2F0) to 9367.9±64.86 kg (S2F3) and, 7983.1±149.79 kg (S3F0) to 9317.7±93.19 kg (S3F3) in S3 spacing which accounted for 18.95%, 19.45% and 16.72% increase in grain yield respectively. Highest grain yield in 5JC among the fertilizer plots ranged from 8806.7±76.77 kg (S1F0) to 9919.9±103.87 kg (S1F3) in S1 spacing, 9051.7±30.18 kg (S2F0) to 10435.0±171.47 kg (S2F3) in S2 spacing and, 9219.4±85.72 kg (S3F0) to 10549.9±40.29 kg (S3F3) in S3 spacing which accounted for 12.64%, 15.28% and 14.43% increase in grain yield respectively.

The grain yield was significantly ($P<0.001$) increased by the increase the period of jhum cycle in all the fertilizer treatments. The maximum grain yield of 7683.5±188.8 kg (S1F3) in 2JC was lower than the minimum yield of 8806.7±76.77 kg (S1F0) of 5JC in S1 spacing. Similar result was also observed in S2 and S3 spacings where the maximum yield in 2JC was comparatively lower than the minimum yield in 5JC.

5.4.7 Harvest Index (HI)

Harvest Index which indicates the yield production per gram of vegetative biomass production showed no significant difference among the fertilizer treatments in all the three spacings as well as the three jhum cycles. But marked significant variations ($P<0.01$) was observed in each fertilizer plots among the jhum cycles. HI increased with increasing jhum cycles. Low HI <0.27 was observed in all the fertilizer plots of S1 spacing in 2JC where as high values of >0.40 was observed in most of the fertilizers plots of S2 and S3 spacings in 5JC.

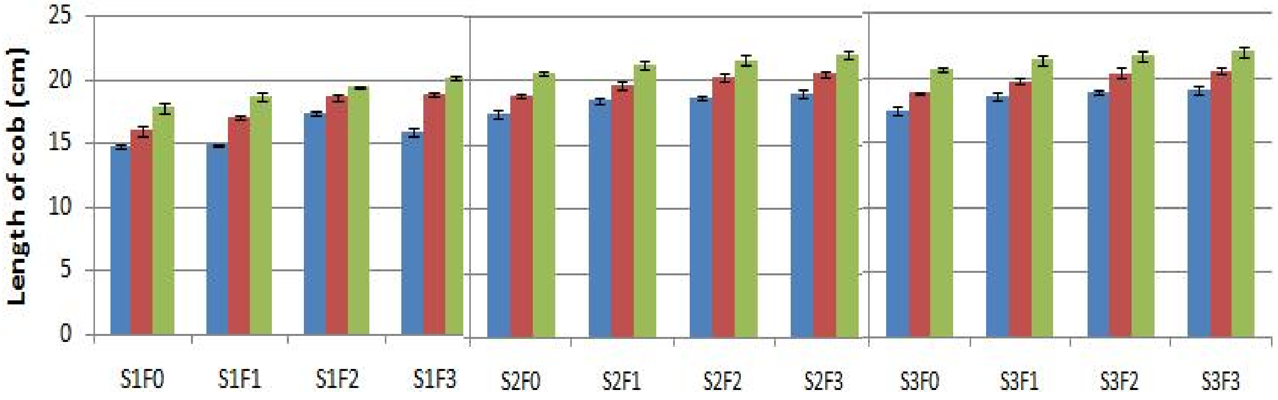


Figure 5.4.1 Effect of fertilizer application on length of cob under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

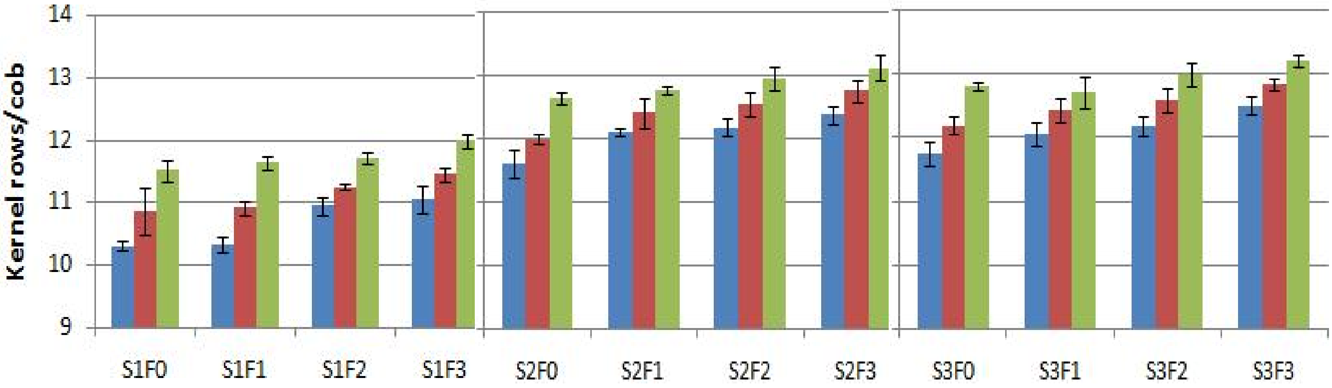


Figure 5.4.2 Effect of fertilizer application on kernel rows per cob under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.4.1: Length of cob under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	S1F1	S1F2	S1F3	LSD (0.05)	S2F0	S2F1	S2F2	S2F3	LSD (0.05)	S3F0	S3F1	S3F2	S3F3	LSD (0.05)
2JC	14.70 ±0.17	14.87 ±0.12	17.31 ±0.14	15.90 ±0.31	*** 1.03	17.48 ±0.30	18.54 ±0.21	18.80 ±0.16	19.07 ±0.36	* 1.06	17.50 ±0.36	18.64 ±0.33	18.98 ±0.17	19.10 ±0.31	* 1.14
3JC	16.00 ±0.40	17.07 ±0.19	18.64 ±0.25	18.87 ±0.18	*** 1.06	18.94 ±0.18	19.69 ±0.25	20.35 ±0.35	20.62 ±0.23	** 0.93	18.90 ±0.12	19.79 ±0.23	20.43 ±0.36	20.58 ±0.24	** 0.89
5JC	17.73 ±0.38	18.62 ±0.30	19.40 ±0.09	20.16 ±0.18	** 0.88	20.66 ±0.12	21.32 ±0.37	21.64 ±0.38	22.08 ±0.31	NS	20.65 ±0.16	21.42 ±0.38	21.75 ±0.38	22.08 ±0.39	NS
LSD (0.05)	** 1.3	*** 1.55	*** 0.75	*** 1.29		*** 1.46	** 1.14	** 1.28	** 1.46		*** 1.4	** 1.14	** 1.31	** 1.48	

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.4.2: No. of Kernel rows per cob under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	S1F1	S1F2	S1F3	LSD (0.05)	S2F0	S2F1	S2F2	S2F3	LSD (0.05)	S3F0	S3F1	S3F2	S3F3	LSD (0.05)
2JC	10.30 ±0.08	10.32 ±0.12	10.95 ±0.15	11.05 ±0.23	* 0.62	11.61 ±0.22	12.10 ±0.07	12.18 ±0.15	12.37 ±0.14	* 0.57	11.74 ±0.18	12.06 ±0.18	12.19 ±0.16	12.50 ±0.13	Ns
3JC	10.86 ±0.37	10.92 ±0.11	11.25 ±0.05	11.45 ±0.12	ns	11.99 ±0.08	12.41 ±0.24	12.54 ±0.19	12.75 ±0.17	ns	12.19 ±0.15	12.43 ±0.19	12.58 ±0.20	12.83 ±0.10	Ns
5JC	11.52 ±0.17	11.64 ±0.10	11.73 ±0.09	11.99 ±0.11	ns	12.63 ±0.09	12.76 ±0.05	12.94 ±0.18	13.12 ±0.20	ns	12.80 ±0.07	12.71 ±0.24	12.99 ±0.19	13.20 ±0.10	Ns
LSD (0.05)	* 1.21	*** 0.31	** 0.48	* 0.94		** 0.63	* 0.65	ns	ns		** 0.61	ns	ns	* 0.7	

* = P<0.05, ** = P<0.01, *** = P<0.001

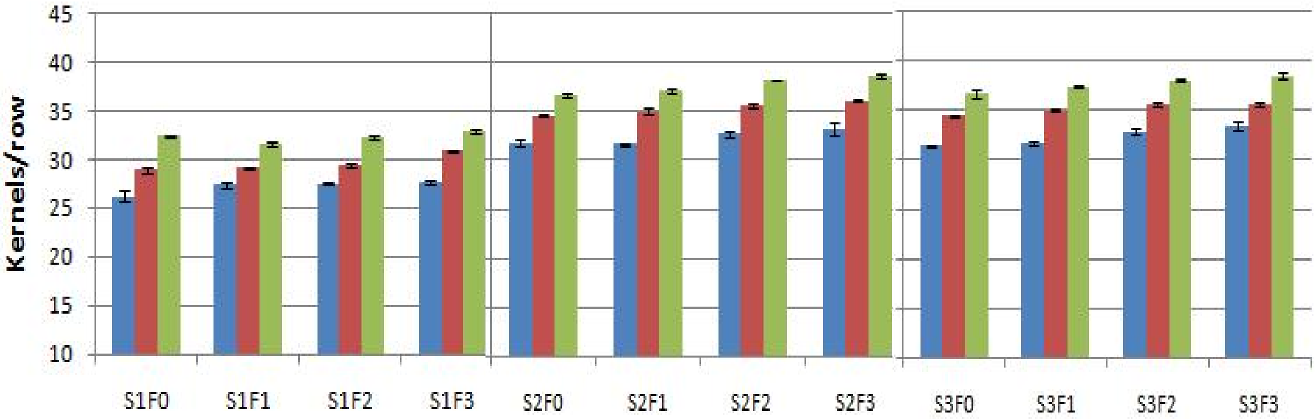


Figure 5.4.3 Effect of fertilizer application on kernels per row under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

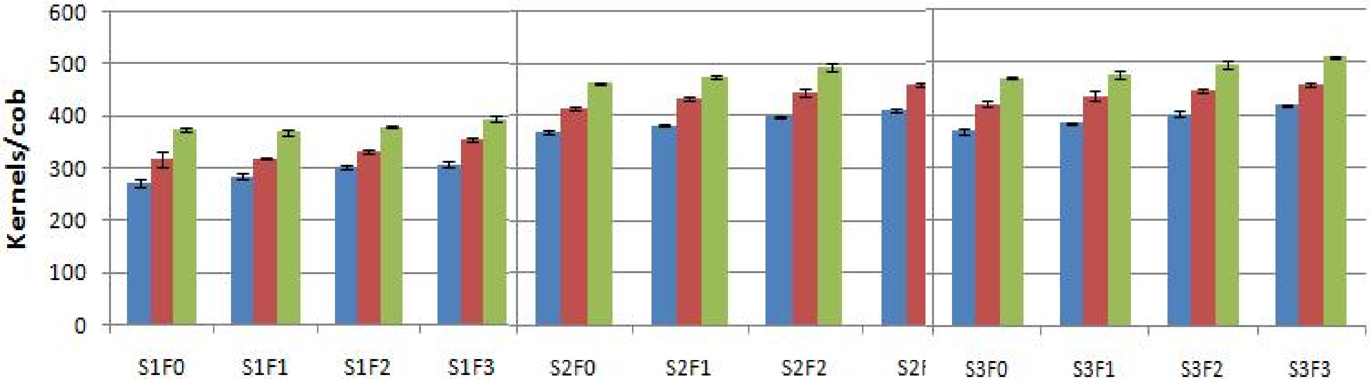


Figure 5.4.4 Effect of fertilizer application on kernels per cob under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.4.3: The effect of fertilizer application on number of kernels per row under S1, S2 and S3 spacing in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	26.24 ±0.48	27.38 ±0.35	27.56 ±0.17	27.75 ±0.18	* 1.13	31.75 ±0.33	31.63 ±0.17	32.79 ±0.32	33.20 ±0.61	NS	31.42 ±0.10	31.79 ±0.21	32.90 ±0.33	33.44 ±0.34	** 1.11
3JC	28.96 ±0.34	29.14 ±0.08	29.43 ±0.26	30.90 ±0.10	*** 1.46	34.59 ±0.11	35.01 ±0.33	35.57 ±0.22	36.11 ±0.14	** 0.97	34.51 ±0.11	35.05 ±0.13	35.53 ±0.22	35.60 ±0.17	** 0.53
5JC	32.40 ±0.12	31.63 ±0.19	32.31 ±0.16	32.90 ±0.29	* 0.68	36.67 ±0.19	37.20 ±0.20	38.17 ±0.04	38.58 ±0.22	*** 0.96	36.70 ±0.38	37.39 ±0.11	38.10 ±0.08	38.53 ±0.30	** 1.14
LSD (0.05)	*** 2.71	*** 1.76	*** 1.87	*** 2		*** 2.07	*** 2.19	*** 2.6	*** 2.47		*** 2.18	*** 2.34	*** 2.57	*** 2.15	

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.4.4: The effect of fertilizer application on number of kernels per cob under S1, S2 and S3 spacing in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	270.44 ±7.03	282.69 ±5.67	301.63 ±2.25	306.59 ±6.78	** 18.94	368.47 ±3.82	382.71 ±1.52	399.30 ±2.47	410.65 ±3.14	*** 11.35	368.99 ±5.35	383.21 ±3.28	401.05 ±6.54	417.93 ±2.61	*** 16.88
3JC	317.57 ±14.90	318.11 ±3.03	331.03 ±3.30	353.72 ±4.86	* 35.61	414.76 ±3.48	434.43 ±4.46	445.97 ±7.62	460.25 ±4.50	** 19.62	420.62 ±6.33	435.73 ±8.29	446.95 ±4.26	456.77 ±5.34	* 21.04
5JC	373.21 ±4.22	368.13 ±4.99	378.91 ±1.97	394.36 ±4.96	* 15.45	462.95 ±1.90	474.68 ±3.50	494.04 ±6.71	506.11 ±5.16	*** 19.36	469.83 ±2.47	475.05 ±8.06	494.90 ±7.86	508.71 ±0.72	** 19.85
LSD (0.05)	*** 47.12	*** 33.42	*** 29.4	*** 40.63		*** 46.28	*** 40.24	*** 46.67	*** 45.86		*** 49.21	*** 39.31	*** 45.9	*** 38.84	

* = P<0.05, ** = P<0.01, *** = P<0.001

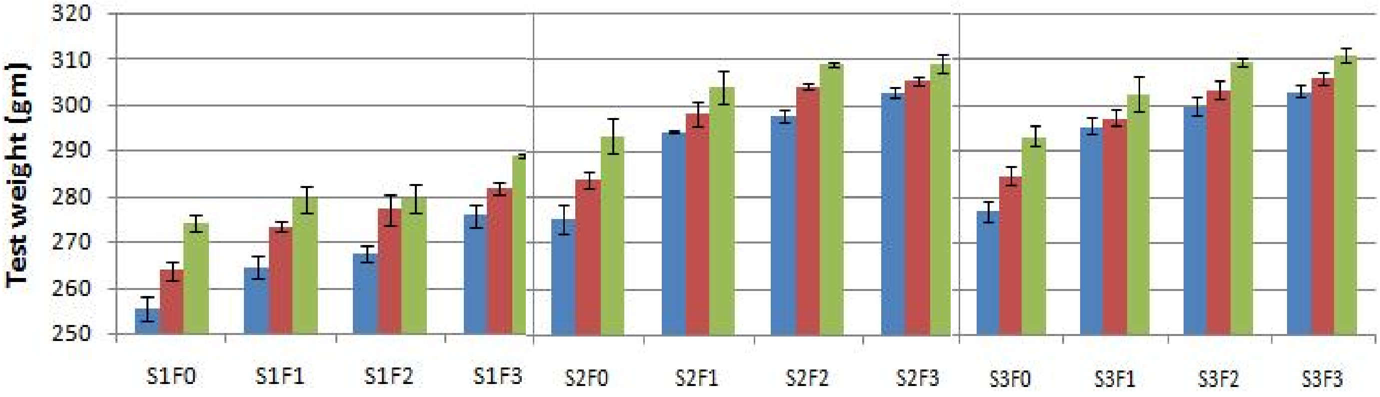


Figure 5.4.5 Effect of fertilizer application on test weight under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

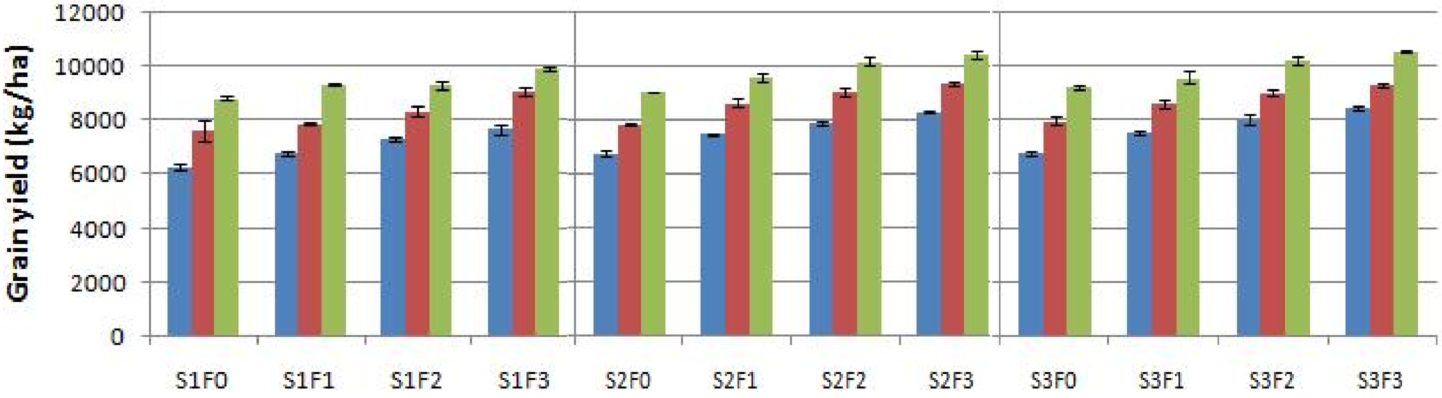


Figure 5.4.6 Effect of fertilizer application on grain yield under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.4.5: Test weight (wt. of 1000 grains) under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	255.33 ±2.60	264.33 ±2.40	267.46 ±1.86	275.67 ±2.40	** 8.20	275.33 ±3.18	294.33 ±0.33	297.67 ±1.45	303.00 ±1.16	*** 8.66	277.00 ±2.08	295.59 ±1.75	300.00 ±2.08	303.28 ±1.36	*** 7.68
3JC	263.67 ±1.86	273.33 ±1.20	277.00 ±3.22	281.67 ±1.45	** 8.33	283.67 ±1.86	298.14 ±2.59	304.33 ±0.67	305.33 ±0.88	*** 6.19	284.67 ±1.45	297.33 ±2.33	303.67 ±0.88	306.00 ±0.58	*** 6.33
5JC	274.20 ±1.73	279.38 ±2.91	279.33 ±3.18	288.73 ±0.37	* 9.34	293.50 ±3.67	304.05 ±3.47	309.00 ±0.58	309.24 ±1.92	* 10.55	293.33 ±2.19	302.67 ±3.84	309.67 ±0.88	311.08 ±1.45	** 8.41
LSD (0.05)	** 8.33	* 9	ns	** 6		* 18.16	Ns	*** 4.66	ns		** 7.66	ns	** 6	** 5.08	

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.4.6: Grain yield under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	6274.4 ±105.1	6790.9 ±93.11	7333.9 ±79.22	7683.5 ±188.8	*** 542.99	6764.2 ±127.26	7509.6 ±37.53	7924.2 ±87.53	8294.7 ±46.24	*** 370.16	6812.9 ±77.69	7551.3 ±75.17	8022.5 ±183.99	8449.9 ±64.56	*** 427.40
3JC	7614.7 ±388.7	7903.8 ±44.11	8337.7 ±178.16	9057.8 ±145.1	* 1153.95	7842.8 ±38.07	8636.0 ±155.82	9047.8 ±149.53	9367.9 ±64.86	*** 731.95	7983.1 ±149.79	8636.3 ±159.29	9048.3 ±99.70	9317.7 ±93.19	*** 681.37
5JC	8806.7 ±76.77	9347.2 ±29.44	9325.0 ±148.95	9919.9 ±103.87	*** 518.23	9051.7 ±30.18	9622.0 ±149.49	10177.5 ±155.52	10435.0 ±171.47	*** 555.46	9219.4 ±85.72	9586.9 ±238.58	10216.8 ±164.96	10549.9 ±40.29	** 629.92
LSD (0.05)	*** 1192.0	*** 1112.9	*** 987.2	*** 862.1		*** 1078.5	*** 986.0	*** 1123.6	*** 1067.0		*** 1170.1	*** 950.57	*** 11025.7	*** 867.7	

* = P<0.05, ** = P<0.01, *** = P<0.001

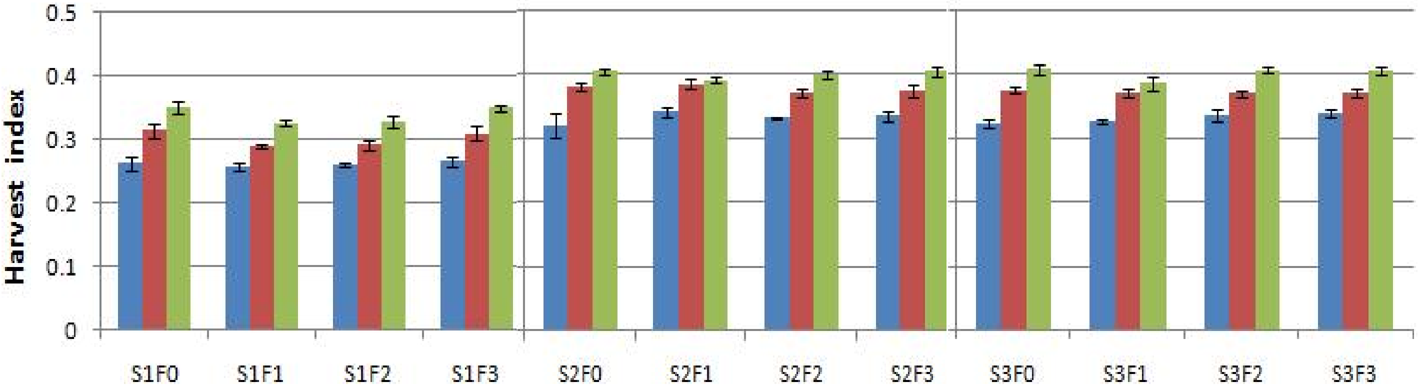


Figure 5.4.7 Effect of fertilizer application on harvest index under different spacing in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.4.7: Harvest Index under different spacing and fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	0.262 ±0.011	0.256 ±0.006	0.259 ±0.004	0.265 ±0.008	ns	0.320 ±0.019	0.341 ±0.008	0.332 ±0.002	0.335 ±0.007	ns	0.323 ±0.007	0.326 ±0.002	0.335 ±0.010	0.339 ±0.006	ns
3JC	0.313 ±0.011	0.289 ±0.004	0.290 ±0.007	0.309 ±0.011	ns	0.381 ±0.007	0.385 ±0.009	0.371 ±0.008	0.374 ±0.008	ns	0.375 ±0.006	0.370 ±0.007	0.370 ±0.005	0.371 ±0.006	ns
5JC	0.350 ±0.009	0.325 ±0.006	0.328 ±0.010	0.348 ±0.006	ns	0.405 ±0.004	0.391 ±0.005	0.400 ±0.006	0.405 ±0.007	ns	0.408 ±0.008	0.385 ±0.011	0.406 ±0.005	0.405 ±0.006	ns
LSD (0.05)	** 0.037	*** 0.033	** 0.031	** 0.038		** 0.061	** 0.044	*** 0.029	** 0.031		*** 0.033	** 0.04	** 0.034	*** 0.031	

* = P<0.05, ** = P<0.01, *** = P<0.001

5.5 Effect of plant spacing on growth parameters

5.5.1 Plant height at 15 DAS

The height at 15 DAS showed no significant ($P<0.05$) effect except in F0 plot in 5JC. Although there was no statistical significance, plants grown under S1 spacing showed comparatively plant height (Figure 5.5.1 & Table 5.5.1).

5.5.2 Plant height at 30 DAS

Plant height at 30DAS showed more significance difference among the S1, S2 and S3 spacings of each fertilizer treatments. In 2JC, significant difference was observed among different spacings with F2 level of fertilizer application. In 3JC, significant difference was observed among different spacings of F0 and F2 fertilizer levels. In 5JC, significance effect of plant spacing was observed under each of the fertilizer levels. In all the Fertilizer levels, F2 and F3 showed comparable values where as plants in S1 showed significantly lower plant height (Figure 5.5.2 & Table 5.5.2).

5.5.3 Plant height at 45 DAS

Plant height at 45DAS also showed low significant response to plant spacing. Significant difference ($P<0.05$) in height occurred among the spacings of all the fertilizer levels. In all the jhum cycles, lowest height occurred in highest plant density where as similar values were observed between S2 and S3 spacings (Table 5.5.3 & Figure 5.5.3).

5.5.4 Plant height at 60 DAS

At 60DAS, significant difference ($P<0.05$) among the three spacing was observed in all the fertilizer levels of 2JC, 3JC and 5JC. The significant different was due to the wide range between S1 to S2 and S3, and no significant difference was observed between S2 and S3. From all the combinations of spacings and fertilizer levels, the lowest height of 162.23±4.12cm occurred in S1F0 plot of 2JC and the maximum height of 232.63±1.36cm was recorded in S3F3 plot of 5JC which accounted for an increased of about 43% from the lowest height (Figure 5.5.4 & Table 5.5.4).

5.5.5 Effect of plant spacing number of leaves at 15 DAS

Similar to plant height, the number of leaves per plant showed no significant variations among the different spacings in all the fertilizer levels. Number of leaves per plant showed narrow range of 5.11 to 5.87 in all the different combinations of fertilizer levels and spacing (Figure 5.5.5 & Table 5.5.5).

5.5.6 Effect of plant spacing number of leaves at 30 DAS

At 30DAS, no statistically significant ($P<0.05$) difference was observed among the different spacing in all the fertilizer levels of 2JC, 3JC and 5JC. The number of leaves per plant showed narrow ranged from 7.08±0.11 (S1F0) of 2JC to 8.0±0.08 (S3F3) of 5JC (Figure 5.5.6 & Table 5.5.6).

5.5.7 Effect of plant spacing number of leaves at 45 DAS

Unlike 15DAS and 30DAS, marked significant variations in number of leaves per plant were observed at 45DAS among different spacings in all the fertilizer levels. Again much lower number of leaves was observed in S1 spacing when compared with that of S2 and S3 spacings. S2 and S3 showed comparable high number of leaves per plant with no statistically significant difference (Figure 5.5.7 & Table 5.5.7).

5.5.8 Effect of plant spacing number of leaves at 60 DAS

Number of leaves per plant at 60DAS also showed significant variations among the different spacings in each of the fertilizer levels. Comparative higher influence of spacing was observed in 2JC. From all the combinations of spacing and fertilizer levels, lowest number of leaves per plant occurred in 10.82±0.03 (S1F0) in 2JC and highest number in 13.68±0.07 (S3F2) of 5JC which accounted for an increase of about 26% (Figure 5.5.8 & Table 5.5.8).

5.5.9 Biomass production

The plant biomass at the time of maturity harvest in terms of dry weight showed significant variations among the S1, S2 and S3 spacings in all the fertilizer levels of 2JC, 3JC and 5JC. Similar to plant height and number of leaves per plant, plants in S1 spacing showed comparatively lower biomass production and similar values were observed in S2 and S3. The lowest plant biomass of 264.50±7.37 gm (S1F0) of 2JC to the highest of 390.93±4.29gm (S3F3) of 5JC accounted for 47.79% increase from the lowest value (Figure 5.5.9 & Table 5.5.9).

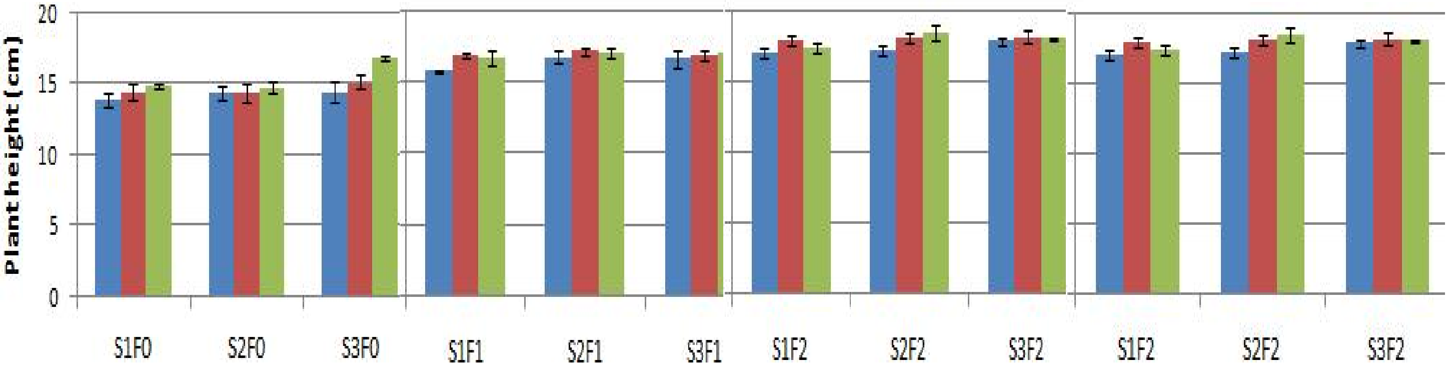


Figure 5.5.1 Effect of spacing on plant height at 15 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

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Figure 5.5.2 Effect of spacing on plant height at 30 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.5.1: Effect of spacing on plant height at 15DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	13.85 ±0.46	14.43 ±0.48	14.48 ±0.67	ns	15.80 ±0.11	16.78 ±0.48	16.70 ±0.60	ns	17.16 ±0.36	17.30 ±0.34	17.97 ±0.29	ns	18.14 ±0.56	18.10 ±0.23	18.39 ±0.28	ns
3JC	14.44 ±0.53	14.37 ±0.62	15.14 ±0.48	ns	16.91 ±0.16	17.20 ±0.31	16.91 ±0.34	ns	17.98 ±0.34	18.19 ±0.30	18.27 ±0.47	ns	18.54 ±0.33	18.89 ±0.23	18.86 ±0.44	ns
5JC	14.90 ±0.12	14.78 ±0.35	16.87 ±0.18	** 1.96	16.72 ±0.54	17.07 ±0.41	17.11 ±0.34	ns	17.44 ±0.42	18.52 ±0.52	18.13 ±0.14	ns	18.63 ±0.29	19.11 ±0.20	18.97 ±0.13	ns

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.5.2: Effect of spacing on plant height at 30DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC SEM	43.16 ±1.95	48.18 ±1.90	50.87 ±2.94	ns	52.88 ±1.96	59.57 ±2.32	61.59 ±2.94	ns	56.60 ±1.34	63.62 ±1.66	61.30 ±SEM	* 7.01	60.66 ±2.71	66.94 ±1.81	65.69 ±1.73	ns
3JC SEM	52.72 ±1.57	61.76 ±2.21	63.46 ±1.96	* 9.03	56.83 ±1.36	62.53 ±1.60	64.90 ±2.43	ns	61.27 ±0.51	69.63 ±1.24	68.67 ±SEM	** 7.40	63.70 ±1.96	71.41 ±3.18	70.44 ±3.39	ns
5JC SEM	68.28 ±1.40	83.79 ±1.54	81.30 ±3.01	** 13.01	71.14 ±2.70	82.32 ±2.09	84.83 ±3.27	* 11.17	74.67 ±1.35	87.18 ±1.83	87.69 ±SEM	** 12.51	79.87 ±1.15	89.38 ±1.57	89.56 ±1.57	** 9.51

* = P<0.05, ** = P<0.01, *** = P<0.001

Figure 5.5.3 Effect of spacing on plant height at 45 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

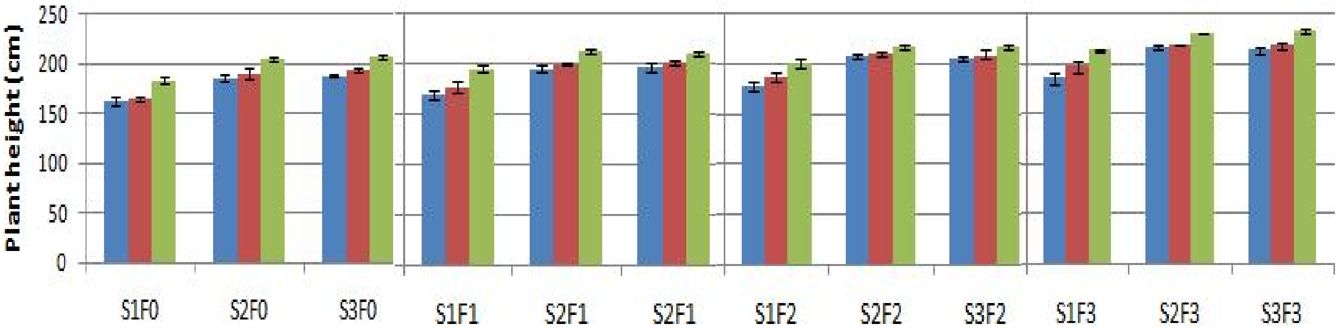


Figure 5.5.4 Effect of spacing on plant height at 60 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.5.3: Effect of spacing on plant height at 45DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	79.74 ±0.84	85.64 ±1.56	83.55 ±1.09	* 5.90	89.46 ±0.85	100.03 ±3.37	98.28 ±2.38	* 8.81	97.52 ±4.27	112.10 ±4.15	115.34 ±3.51	* 2.58	101.92 ±2.01	118.50 ±4.15	122.42 ±6.62	* 16.58
3JC	89.60 ±3.32	97.83 ±2.92	106.73 ±2.98	* 17.13	101.63 ±1.61	103.21 ±2.47	111.11 ±3.35	ns	109.35 ±1.43	118.93 ±2.37	122.84 ±2.54	* 9.57	121.42 ±0.78	131.67 ±4.49	131.26 ±1.24	ns
5JC	142.34 ±3.56	159.81 ±3.50	153.94 ±2.40	* 11.60	157.08 ±2.65	166.56 ±2.89	168.37 ±1.20	* 9.47	163.85 ±1.81	171.34 ±4.21	175.67 ±1.45	ns	170.67 ±2.03	184.26 ±3.14	181.31 ±1.22	* 10.64

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.5.4: Effect of spacing on plant height at 60DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	162.23 ±4.12	185.61 ±3.38	188.32 ±1.48	** 23.37	169.03 ±3.84	195.74 ±3.36	197.45 ±4.72	** 26.71	177.50 ±5.02	207.87 ±2.62	206.25 ±1.92	** 28.75	184.63 ±5.14	215.34 ±2.49	212.72 ±3.29	** 28.08
3JC	165.38 ±2.10	190.51 ±5.36	193.98 ±2.55	** 25.13	177.44 ±5.60	200.58 ±1.64	202.05 ±2.01	** 23.13	186.50 ±4.55	210.98 ±2.39	209.45 ±4.19	** 22.94	196.14 ±5.32	218.72 ±1.00	217.52 ±2.60	** 21.37
5JC	183.33 ±3.84	205.52 ±2.04	206.89 ±1.42	** 22.18	194.88 ±3.47	212.32 ±2.92	211.03 ±1.84	** 16.15	201.41 ±4.70	217.45 ±2.10	217.83 ±2.27	*	212.54 ±1.36	229.92 ±0.28	232.63 ±1.36	*** 17.37

* = P<0.05, ** = P<0.01, *** = P<0.001

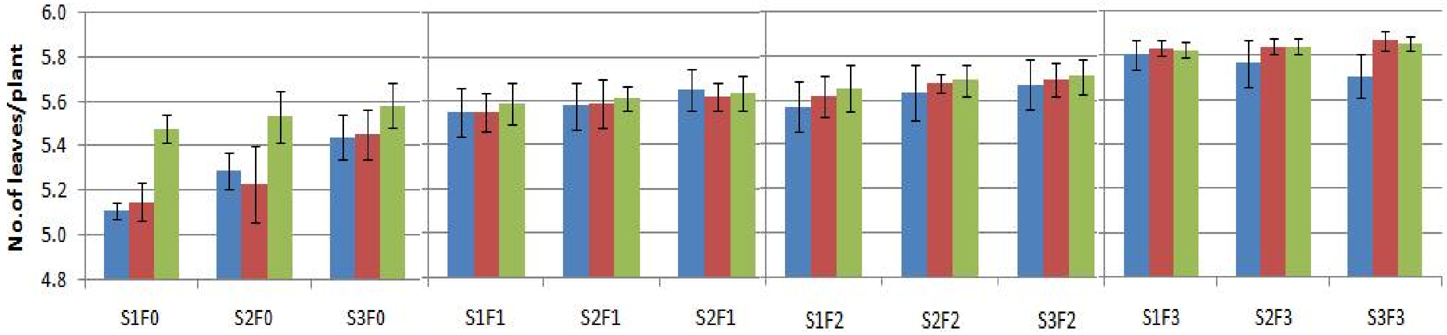


Figure 5.5.5 Effect of spacing on number of leaves per plant at 15 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

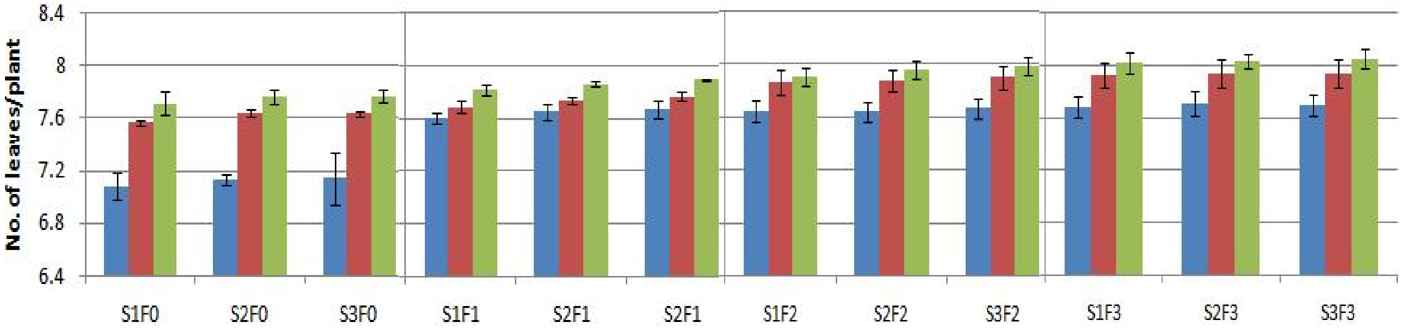


Figure 5.5.6 Effect of spacing on number of leaves per plant at 30 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.5.5: Effect of spacing on number of leaves per plant at 15DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	5.11	5.29	5.44		5.55	5.58	5.65		5.57	5.63	5.67		5.81	5.77	5.71	
SEM	±0.04	±0.08	±0.10	ns	±0.11	±0.11	±0.10	ns	±0.11	±0.13	±0.11	ns	±0.07	±0.11	±0.10	ns
3JC	5.15	5.23	5.45		5.55	5.59	5.62		5.61	5.68	5.69		5.83	5.84	5.87	
SEM	±0.09	±0.17	±0.11	ns	±0.09	±0.11	±0.06	ns	±0.09	±0.04	±0.08	ns	±0.03	±0.03	±0.05	ns
5JC	5.48	5.53	5.58		5.59	5.61	5.64		5.65	5.69	5.71		5.83	5.84	5.86	
SEM	±0.06	±0.12	±0.10	ns	±0.09	±0.06	±0.08	ns	±0.11	±0.07	±0.08	ns	±0.03	±0.03	±0.03	ns

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.5.6: Effect of spacing on number of leaves per plant at 30DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
	7.08	7.60	7.65	7.68	**	7.13	7.65	7.64	7.71	**	7.14	7.67	7.67	7.69	*
2JC	±0.11	±0.04	±0.08	±0.08	0.52	±0.04	±0.06	±0.07	±0.10	0.51	±0.20	±0.07	±0.08	±0.08	0.53
	7.57	7.69	7.86	7.92	*	7.64	7.74	7.88	7.94		7.63	7.77	7.90	7.94	
3JC	±0.02	±0.04	±0.09	±0.10	0.29	±0.02	±0.03	±0.09	±0.10	ns	±0.02	±0.03	±0.09	±0.10	ns
	7.71	7.82	7.91	8.02		7.76	7.87	7.96	8.03	*	7.77	7.89	7.99	8.05	*
5JC	±0.09	±0.04	±0.07	±0.08	ns	±0.06	±0.02	±0.07	±0.06	0.20	±0.05	±0.00	±0.07	±0.08	0.21
LSD	**	*				***	*				*	*			
(0.05)	0.48	0.21	ns	ns		0.5	0.21	ns	ns		0.49	0.22	ns	ns	

* = P<0.05, ** = P<0.01, *** = P<0.001

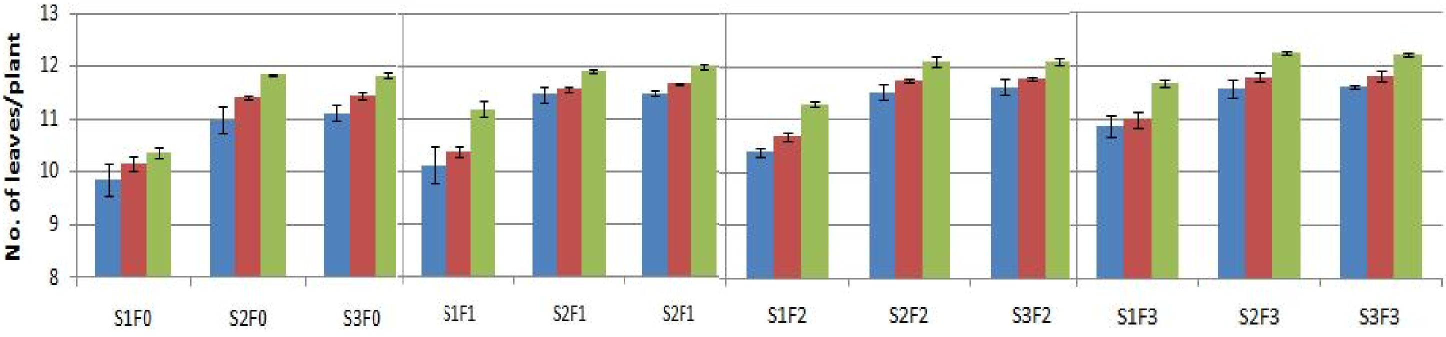


Figure 5.5.7 Effect of spacing on number of leaves per plant at 45 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

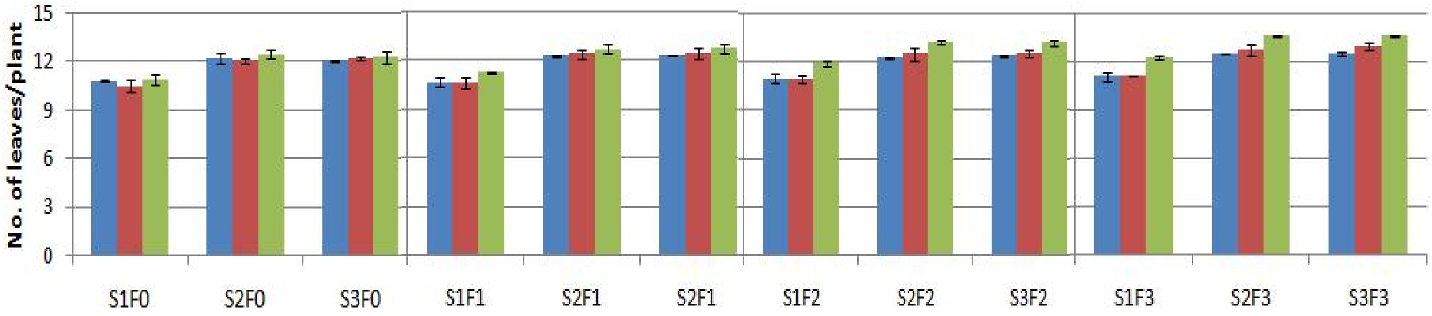


Figure 5.5.8 Effect of spacing on number of leaves per plant at 60 DAS under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.5.7: Effect of spacing on number of leaves per plant at 45DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	9.85 ±0.31	10.98 ±0.25	11.13 ±0.15	* 1.12	10.13 ±0.36	11.48 ±0.15	11.50 ±0.05	** 1.34	10.39 ±0.07	11.53 ±0.14	11.63 ±0.14	*** 1.14	10.87 ±0.20	11.59 ±0.17	11.61 ±0.03	* 0.71
3JC	10.15 ±0.13	11.40 ±0.03	11.45 ±0.06	*** 1.25	10.37 ±0.10	11.57 ±0.05	11.68 ±0.01	*** 1.20	10.68 ±0.07	11.74 ±0.02	11.78 ±0.03	*** 1.05	11.00 ±0.15	11.80 ±0.09	11.81 ±0.09	** 0.79
5JC	10.37 ±0.09	11.84 ±0.01	11.83 ±0.05	*** 17.43	11.20 ±0.15	11.92 ±0.02	12.01 ±0.06	** 0.71	11.30 ±0.06	12.10 ±0.10	12.11 ±0.08	*** 0.80	11.67 ±0.07	12.25 ±0.03	12.21 ±0.04	*** 0.54

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.5.8: Effect of spacing on number of leaves per plant at 60DAS under different levels of fertilizer applications in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S1F1**	**S1F2**	**S1F3**	**LSD (0.05)**	**S2F0**	**S2F1**	**S2F2**	**S2F3**	**LSD (0.05)**	**S3F0**	**S3F1**	**S3F2**	**S3F3**	**LSD (0.05)**
2JC	10.59 ±0.17	10.71 ±0.28	11.25 ±0.07	11.50 ±0.09	* 0.65	11.98 ±0.05	12.35 ±0.05	12.34 ±0.06	12.56 ±0.02	*** 0.21	12.09 ±0.06	12.34 ±0.02	12.41 ±0.04	12.55 ±0.06	** 0.21
3JC	10.49 ±0.36	10.69 ±0.32	10.97 ±0.24	11.17 ±0.05	ns	12.06 ±0.15	12.44 ±0.30	12.54 ±0.37	12.78 ±0.34	ns	12.18 ±0.11	12.45 ±0.33	12.58 ±0.27	12.99 ±0.25	ns
5JC	10.87 ±0.34	11.32 ±0.07	11.98 ±0.17	12.34 ±0.14	** 1.02	12.48 ±0.28	12.75 ±0.31	13.24 ±0.15	13.68 ±0.07	* 0.76	12.27 ±0.54	12.80 ±0.30	13.25 ±0.18	13.66 ±0.05	ns
LSD (0.05)	ns	ns	* 0.73	*** 0.84		ns	ns	ns	* 0.9		ns	ns	* 0.67	** 0.67	

*= P<0.05, ** = P<0.01, *** = P<0.001

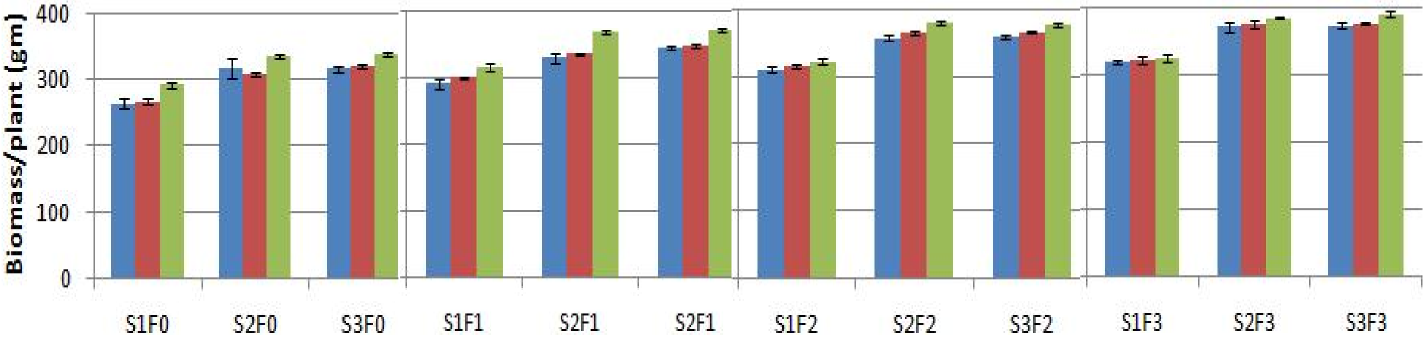


Figure 5.5.9 Effect of spacing on biomass production at maturity harvest under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error

Table 5.5.9: Effect of spacing on biomass production at maturity harvest under different levels of fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	264.50 ±7.37	318.50 ±14.40	316.50 ±3.97	* 52	292.50 ±7.70	331.00 ±6.61	347.00 ±3.50	** 38.5	311.50 ±4.44	358.50 ±4.58	359.65 ±3.16	*** 47	319.50 ±3.12	371.50 ±6.08	374.20 ±4.09	*** 52
3JC	267.77 ±4.91	308.55 ±3.87	319.66 ±3.01	*** 40.78	301.12 ±2.11	336.59 ±2.24	350.15 ±3.33	*** 13.55	316.10 ±3.02	366.17 ±2.34	367.19 ±1.37	*** 50.07	322.38 ±6.39	376.03 ±5.67	377.08 ±2.28	*** 53.64
5JC	292.60 ±4.50	335.80 ±2.75	337.72 ±2.78	*** 43.19	316.87 ±5.96	369.59 ±2.84	373.41 ±3.95	*** 52.72	323.40 ±5.30	381.54 ±2.01	377.46 ±2.96	*** 54.05	327.13 ±5.96	386.11 ±1.79	390.93 ±4.29	*** 58.98

*= P<0.05, ** = P<0.01, *** = P<0.001

5.6 Effect of plant spacing on yield parameters

5.6.1 Length of cob

Length of cob showed highly significant (P<0.001) difference among the three spacing in each of the fertilizer levels in 2JC. Significant (P<0.05) difference was also found among the three spacings in all the fertilizer levels of 3JC and 5JC. Length of cob of S2 and S3 showed comparable values where as considerably shorter length was observed in S1 spacing. The difference from the shortest length of 14.70±0.17 (S1F0)cm in 2JC to the longest of 22.08±0.39 cm(S3F3) in 5JC accounted for about 50% increase from the shortest length (Figure 5.6.1 & Table 5.6.1).

5.6.2 Kernel rows per cob

Kernel rows per cob also showed significant (P<0.05) variations among difference spacings with much lesser number of rows in S1 spacing when compared with S2 and S3. The increase in kernel rows per cob from the minimum and maximum values in each fertilizer levels accounted for 13.98% in F0, 16.79% in F1, 11.36% in F2 and 13.14% in F3 of 2JC. In 3JC, the increase from the from the minimum and maximum values in each fertilizer levels accounted for 12.20% in F0, 13.86% in F1, 11.86% in F2 and 12.08% in F3. Lower range between the minimum and maximum values was observed in 5JC which accounted for 11.13% increase in F0, 9.17% in F1, 10.75% in F2 and 10.14% in F3 respectively (Figure 5.6.2 & Table 5.6.2).

The ranged between the lowest number of kernel rows per cob in 10.30±0.08 (S1F0) in 2JC to the highest of 13.20 (S3F3) in 5JC accounted for 28.15% increase from the lowest value.

5.6.3 Kernel per row

The number of kernels per row showed highly significant (P<0.001) variations among the three spacings in all the fertilizer levels of 2JC, 3JC and 5JC. S2 and S3 showed no significant difference where as S1 showed significant difference with S2 and S3 due to its comparatively lower values in all the fertilizer levels. From all the combinations of spacings, fertilizer levels and different jhum cycles, the difference between the lowest value of 26.24±0.48 (S1F0) in 2JC to the highest value of 38.58±0.30 (S3F2) in 5JC accounted for 47% increase from the lowest value (Figure 5.6.3 & Table 5.6.3).

5.6.4 Kernels per cob

The number of kernels per cob also showed highly significant (P<0.001) variations between S1 with S2 and S3 in all the fertilizer application levels. The difference between the minimum and the maximum number of kernels per cob accounted for 19.72 in F0, 16.10% in F1, 19.37% in F2 and 20.50% in F3 of 2JC; 18.10% in F0, 20.27% in F1, 20.72% in F2 and 15.21% F3 in 3JC and, 13.27% in F0, 18.20% in F1, 17.91% in F2 and 17.12% in F3 of 5JC (Figure 5.6.4 & Table 5.6.4).

Among the different combinations of spacings and fertilizer levels in 2JC, 3JC and 5JC, the difference between the lowest number of kernels per cob of 270.44±7.03 (S1F0) in 2JC to the highest number of 508.71 (S3F3) in 5JC accounted for 88% increase from the lowest value.

5.6.5 Test weight

The test weight showed significant (P<0.05) difference among the S1, S2 and S3 spacings which was due to the marked lower values in S1 spacing in all the fertilizer levels. The combination of wider spacing with higher level of fertilizer application resulted in the increase in test weight. The lowest TW of 255.33±2.60 gm (S1F0) in 2JC to 311.08±1.45 gm (S3F3) in 5JC accounted for 21.83% from the minimum value (Figure 5.6.5 & Table 5.6.5).

5.6.6 Grain yield

Grain yield was significantly ($P<0.05$) affected by plant spacing in all fertilizer levels except in F0 and F3 in 3JC and, F1 in 5JC. Lower grain yield per hectare was observed in highest density spacing. The range from the minimum grain yield to the maximum yield among the three spacing accounted for 8.58%, 11.19%, 9.38% and 9.97% increase in F0, F1, F2 and F3 of 2JC; 4.83%, 9.26%, 8.52% and 2.86% in F0, F1, F2 and F3 of 3J and, 4.68%, 2.56%, 9.56% and 6.35% increase in F0, F1, F2 and F3 of 5JC (Figure 5.6.6 & Table 5.6.6).

5.6.7 Harvest Index

Harvest index was significantly ($P<0.05$) influenced by plant spacing in which the highest density spacing of S1 resulted in reduction of HI. The maximum HI in 2JC, 3JC and 5JC were 0.339±0.006 (S3F3), 0.385±0.009 (S2F1) and 0.408±0.008 (S3F0) respectively. Comparatively higher HI was observed in all the plots of 5JC (Figure 5.6.7 & Table 5.6.7).

Figure 5.6.1 Effect of spacing on length of cob under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error

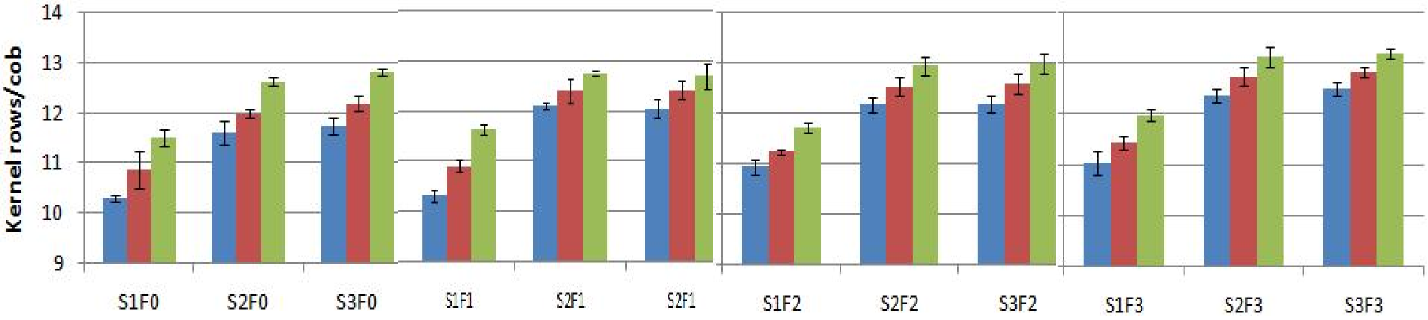


Figure 5.6.2 Effect of spacing on kernel rows per cob under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error

Table 5.6.1: Effect of spacing on length of cob under different levels of fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	14.70 ±0.17	17.48 ±0.30	17.50 ±0.36	*** 2.77	14.87 ±0.12	18.54 ±0.21	18.64 ±0.33	*** 3.67	17.31 ±0.14	18.80 ±0.16	18.98 ±0.17	*** 1.49	15.90 ±0.31	19.07 ±0.36	19.10 ±0.31	*** 3.16
3JC	16.00 ±0.40	18.94 ±0.18	18.90 ±0.12	*** 2.9	17.07 ±0.19	19.69 ±0.25	19.79 ±0.23	*** 2.62	18.64 ±0.25	20.35 ±0.35	20.43 ±0.36	* 1.71	18.87 ±0.18	20.62 ±0.23	20.58 ±0.24	** 1.71
5JC	17.73 ±0.38	20.66 ±0.12	20.65 ±0.16	*** 2.91	18.62 ±0.30	21.32 ±0.37	21.42 ±0.38	** 2.69	19.40 ±0.09	21.64 ±0.38	21.75 ±0.38	** 2.23	20.16 ±0.18	22.08 ±0.31	22.08 ±0.39	** 1.91

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.6.2: Effect of spacing on kernel rows per cob under different levels of fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	10.30 ±0.08	11.61 ±0.22	11.74 ±0.18	** 1.30	10.32 ±0.12	12.10 ±0.07	12.06 ±0.18	*** 1.73	10.95 ±0.15	12.18 ±0.15	12.19 ±0.16	** 1.23	11.05 ±0.23	12.37 ±0.14	12.50 ±0.13	** 1.32
3JC	10.86 ±0.37	11.99 ±0.08	12.19 ±0.15	* 1.12	10.92 ±0.11	12.41 ±0.24	12.43 ±0.19	** 1.49	11.25 ±0.05	12.54 ±0.19	12.58 ±0.20	** 1.29	11.45 ±0.12	12.75 ±0.17	12.83 ±0.10	*** 1.30
5JC	11.52 ±0.17	12.63 ±0.09	12.80 ±0.07	*** 1.10	11.64 ±0.10	12.76 ±0.05	12.71 ±0.24	** 1.06	11.73 ±0.09	12.94 ±0.18	12.99 ±0.19	** 1.21	11.99 ±0.11	13.12 ±0.20	13.20 ±0.10	** 1.13

* = P<0.05, ** = P<0.01, *** = P<0.001

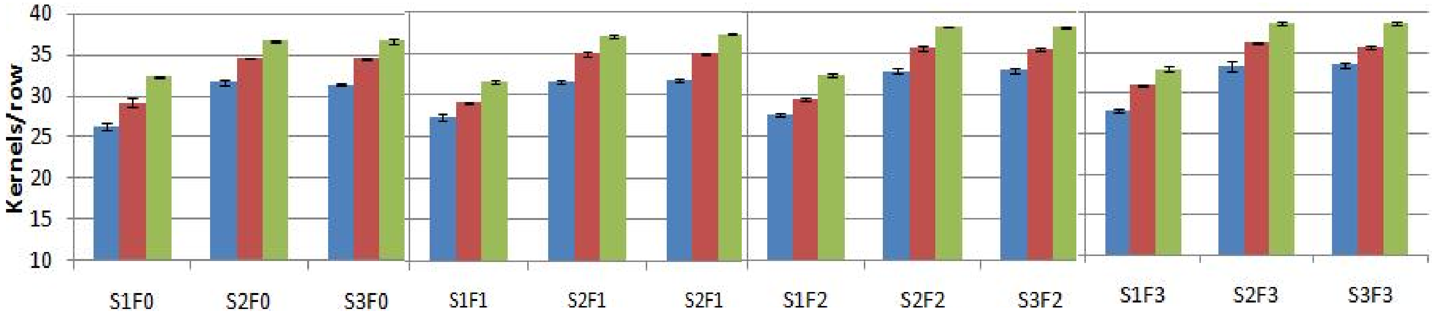


Figure 5.6.3 Effect of spacing on kernels per row under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

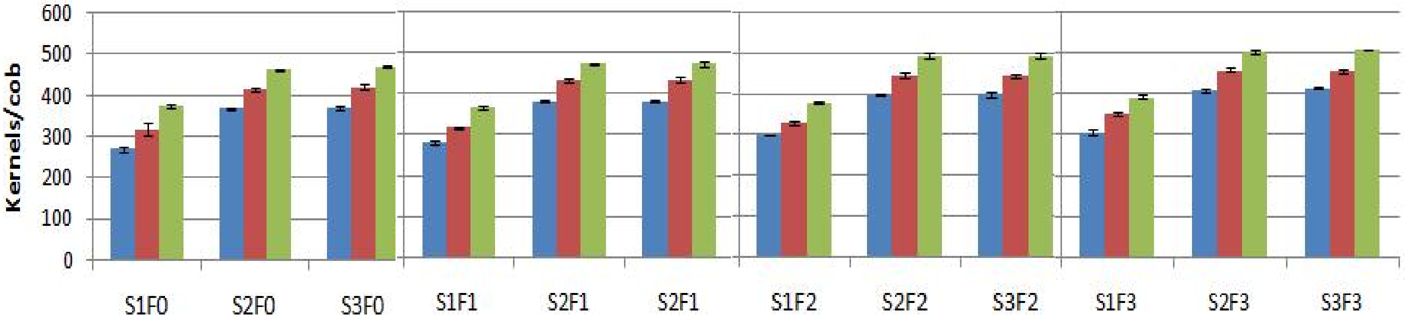
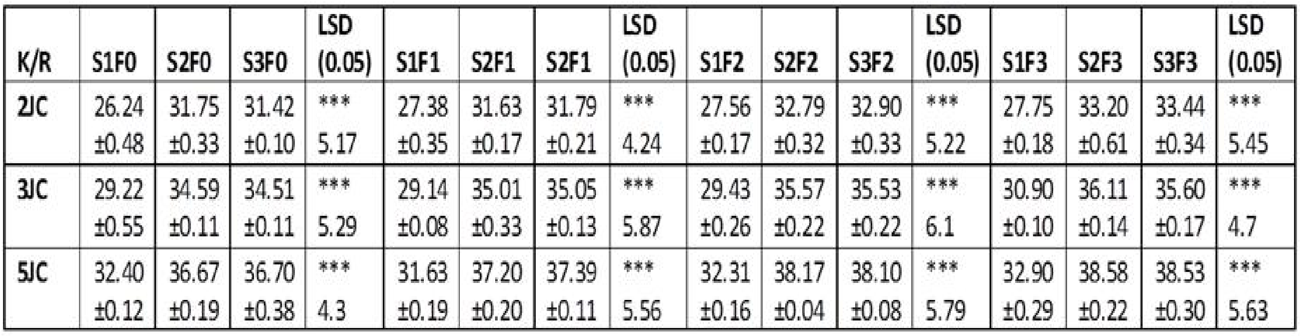


Figure 5.6.4 Effect of spacing on kernels per cob under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table5.6.3: Effect of spacing on kernel per row under different levels of fertilizer application in 2, 3 and 5 years Jhum cycles. Mean ±SEM



K/R	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S2F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	26.24 ±0.48	31.75 ±0.33	31.42 ±0.10	*** 5.17	27.38 ±0.35	31.63 ±0.17	31.79 ±0.21	*** 4.24	27.56 ±0.17	32.79 ±0.32	32.90 ±0.33	*** 5.22	27.75 ±0.18	33.20 ±0.61	33.44 ±0.34	*** 5.45
3JC	29.22 ±0.55	34.59 ±0.11	34.51 ±0.11	*** 5.29	29.14 ±0.08	35.01 ±0.33	35.05 ±0.13	*** 5.87	29.43 ±0.26	35.57 ±0.22	35.53 ±0.22	*** 6.1	30.90 ±0.10	36.11 ±0.14	35.60 ±0.17	*** 4.7
5JC	32.40 ±0.12	36.67 ±0.19	36.70 ±0.38	*** 4.3	31.63 ±0.19	37.20 ±0.20	37.39 ±0.11	*** 5.56	32.31 ±0.16	38.17 ±0.04	38.10 ±0.08	*** 5.79	32.90 ±0.29	38.58 ±0.22	38.53 ±0.30	*** 5.63

* = P<0.05, ** = P<0.01, *** = P<0.001

Table5.6.4: Effect of spacing on kernel per cob under different levels of fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	10.30 ±0.08	11.61 ±0.22	11.74 ±0.18	** 1.30	10.32 ±0.12	12.10 ±0.07	12.06 ±0.18	*** 1.73	10.95 ±0.15	12.18 ±0.15	12.19 ±0.16	** 1.23	11.05 ±0.23	12.37 ±0.14	12.50 ±0.13	** 1.32
3JC	10.86 ±0.37	11.99 ±0.08	12.19 ±0.15	* 1.12	10.92 ±0.11	12.41 ±0.24	12.43 ±0.19	** 1.49	11.25 ±0.05	12.54 ±0.19	12.58 ±0.20	** 1.29	11.45 ±0.12	12.75 ±0.17	12.83 ±0.10	*** 1.30
5JC	11.52 ±0.17	12.63 ±0.09	12.80 ±0.07	*** 1.10	11.64 ±0.10	12.76 ±0.05	12.71 ±0.24	** 1.06	11.73 ±0.09	12.94 ±0.18	12.99 ±0.19	** 1.21	11.99 ±0.11	13.12 ±0.20	13.20 ±0.10	** 1.13

* = P<0.05, ** = P<0.01, *** = P<0.001

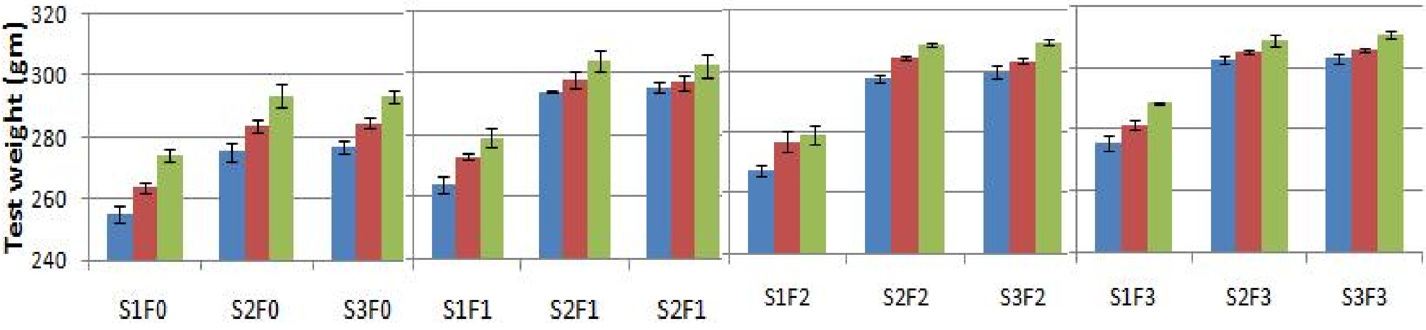


Figure 5.6.5 Effect of spacing on test weight under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Figure 5.6.6 Effect of spacing on grain yield under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table5.6.5: Effect of spacing on Test weight (1000 grain wt.) under different levels of fertilizer application levels in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	255.33 ±2.60	275.33 ±3.18	277.00 ±2.08	** 20	264.33 ±2.40	294.33 ±0.33	295.59 ±1.75	*** 30	267.46 ±1.86	297.67 ±1.45	300.00 ±2.08	*** 30.20	275.67 ±2.40	303.00 ±1.16	303.28 ±1.36	*** 27.33
3JC	263.67 ±1.86	283.67 ±1.86	284.67 ±1.45	*** 20	273.33 ±1.20	298.14 ±2.59	297.33 ±2.33	*** 24	277.00 ±3.22	304.33 ±0.67	303.67 ±0.88	*** 26.66	281.67 ±1.45	305.33 ±0.88	306.00 ±0.58	*** 23.66
5JC	274.20 ±1.73	293.50 ±3.67	293.33 ±2.19	** 19.13	279.38 ±2.91	304.05 ±3.47	302.67 ±3.84	** 23.28	279.33 ±3.18	309.00 ±0.58	309.67 ±0.88	*** 29.66	288.73 ±0.37	309.24 ±1.92	311.08 ±1.45	*** 20.51

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5.6.6: Effect of spacing on grain yield under different levels of fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM.

	S1F0	**S2F0**	**S3F0**	**LSD (0.05)**	**S1F1**	**S2F1**	**S3F1**	**LSD (0.05)**	**S1F2**	**S2F2**	**S3F2**	**LSD (0.05)**	**S1F3**	**S2F3**	**S3F3**	**LSD (0.05)**
2JC	6274.4 ±105.1	6764.2 ±127.3	6813.0 ±77.7	* 489.82	6790.9 ±93.1	7509.7 ±37.5	7551.4 ±75.2	*** 718.71	7333.9 ±79.2	7924.2 ±87.5	8022.5 ±184.0	* 590.29	7683.5 ±188.9	8294.8 ±46.2	8449.9 ±64.6	** 611.28
3JC	7614.7 ±388.8	7842.8 ±38.1	7983.1 ±149.8	ns	7903.9 ±44.1	8636.0 ±155.8	8636.3 ±159.3	* 732.13	8337.8 ±178.2	9047.9 ±149.5	9048.3 ±99.7	* 710.10	9057.8 ±145.2	9368.0 ±64.9	9317.7 ±93.2	ns
5JC	8806.8 ±76.8	9051.7 ±30.2	9219.5 ±85.7	* 244.91	9347.2 ±29.4	9622.1 ±149.5	9586.9 ±238.6	ns	9325.0 ±148.9	10177.6 ±155.5	10216.8 ±165.0	* 852.53	9919.9 ±103.9	10435.0 ±171.5	10549.9 ±40.3	* 515.07

* = P<0.05, ** = P<0.01, *** = P<0.001

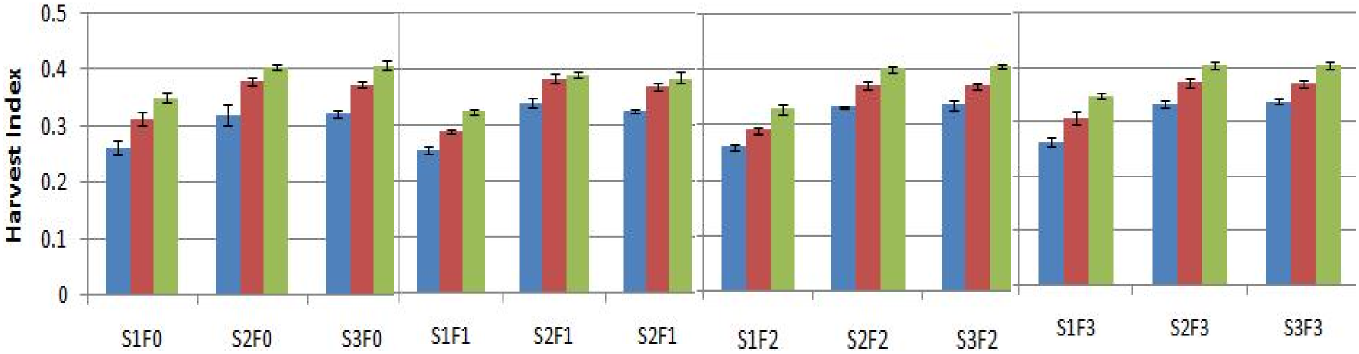


Figure 5.6.7 Effect of spacing on harvest index under different fertilizer application levels in 2 years, 3 years and 5 years jhum cycles. Vertical line indicates standard error.

Table 5.6.7: Effect of spacing on Harvest Index (HI) under different levels fertilizer application in 2, 3 and 5 years jhum cycles. Mean ±SEM

	S1F0	S2F0	S3F0	LSD (0.05)	S1F1	S2F1	S3F1	LSD (0.05)	S1F2	S2F2	S3F2	LSD (0.05)	S1F3	S2F3	S3F3	LSD (0.05)
2JC	0.262 ±0.011	0.320 ±0.019	0.323 ±0.007	* 0.05	0.256 ±0.006	0.341 ±0.008	0.326 ±0.002	*** 0.07	0.259 ±0.004	0.332 ±0.002	0.335 ±0.010	*** 0.07	0.265 ±0.008	0.335 ±0.007	0.339 ±0.006	*** 0.07
3JC	0.313 ±0.011	0.381 ±0.007	0.375 ±0.006	** 0.06	0.289 ±0.004	0.385 ±0.009	0.370 ±0.007	*** 0.08	0.290 ±0.007	0.371 ±0.008	0.370 ±0.005	*** 0.07	0.309 ±0.011	0.374 ±0.008	0.371 ±0.006	** 0.06
5JC	0.350 ±0.009	0.405 ±0.004	0.408 ±0.008	** 0.05	0.325 ±0.006	0.391 ±0.005	0.385 ±0.011	** 0.06	0.328 ±0.010	0.400 ±0.006	0.406 ±0.005	*** 0.07	0.348 ±0.006	0.405 ±0.007	0.405 ±0.006	** 0.06

* = P<0.05, ** = P<0.01, *** = P<0.001

Chapter – VI

Discussion

6.1 Effect of NPK fertilizer on growth performance

6.1.1 Effect of fertilizer applications on plant height

The sowing of seeds on 24 March coincided with the summer rain resulted in the early germination of seeds. The significant difference in height among the fertilizer different levels of fertilizer application with better plant height under higher rate of fertilizer application may be due to the improvement of seedling vigor by the availability of soil nutrients for the developing seedlings. Improvement of seedling vigor is necessary for the survival and yield of crops plants. The minimum height in plots without fertilizer application and the increasing in plant height with increasing in fertilizer application indicated the early response of maize seedlings to soil nutrient availability. The non significant difference in plant height among the jhum cycles in most of the fertilizer levels indicated the low response to different jhum cycles a the initial stage of growth.

The plant height under different fertilizer levels at 30DAS exhibited a marked shift from that of the plant height at 15DAS as highly significant difference occurred among the jhum cycles. Less significant variations among the fertilizer plots in each of the spacings may be due to depletion of soil nutrients due to leaching by rainfall and that the highly significant difference among the jhum cycles may be attributed to the different natural soil condition among the jhum cycles.

The increase in the significant level from that of 30DAS in plant height of maize under different fertilizer levels may be due to response of plants to the second dose of NPK fertilizer which was applied at 30DAS. The higher percentage increase from the minimum height to the maximum height in 2JC and 3JC may be due to the high influence of nutrient application in these two jhum sites of poorer soil nutrient properties than the 5JC. High growth rate in height during the period of 30 to 45DAS coincided with the increasing in rainfall which enhances growth performance. Compared to 2JC and 3JC, higher growth rate was observed among the plants in the fertilizer plots of 5JC.

Measurement of plant height at 60DAS showed highest growth rate in plants under different fertilizer levels in 2JC and 3JC where as reduction is growth rate was observed in 5JC when compared with that of the growth rate at 45DAS. Despite of the wide range in plant height between plants of 2JC and 3JC to that of the corresponding treatment in 5JC in 45DAS, the range become narrower due to the high growth rate of plants in 2JC and 3JC.

From the observation plant growth performance in terms of height, it is obvious that soil nutrient deficit is one of the major limiting factors for plant growth in the different jhum cycles of Mizoram. Fertilizer application and longer jhum cycle induced vigorous growth during the 15 to 45DAS. Plant height is one of the crucial factors which determines the survival and productivity of the plant. Higher plant height has better light interception which facilitates higher photosynthetic rates under favourable condition. From the observation of highest plant height corresponding with highest fertilizer application, it might be suggested that increase the levels of NPK fertilizer application might still enhance the growth performance of the mimpui variety of maize.

6.1.2 Effect of NPK fertilizer application on number of leaves per plant

The non-significant and low significant variations in number of leaves per plant in all the fertilizer levels as well as among the jhum cycles indicted that the leaves production was uniform regardless of soil nutrient input and difference in jhum cycles. Although the highly significant variation in plant height at this growth stage did not induced much variations in leaves production as all the plants under different fertilizer application levels as well as jhum cycles showed narrow range in number of leaves per plant.

As the growth progressed, higher variations among the plants under different fertilizer applications as well as the jhum cycles indicated that the influence of soil nutrient availability became more evident. More variations were observed at 45DAS in the number of leaves per plant. Similar trend with that of plant height of increasing number of leaves with increasing fertilizer application levels as well as the jhum cycles was still observed at 45DAS.

Despite of the higher significant difference in height at 60DAS, the number of leaves at 60DAS showed lesser significant levels between fertilizer plots as well as the jhum cycles. This indicated that the number leaf production was less affected by fertilizer input and jhum cycles, and the higher variations in plant height did not necessarily induced greater number of leaves per plant. Thus, the increase in height might be due to the increase in internode length rather than the production of more nodes for leaf production.

6.1.3 Effect of NPK fertilizer onpPlant dry biomass

The plant biomass production was also strongly affected by fertilizer applications. Under the same spacing, the occurrence of lowest biomass production in plots without fertilizer input and the increase with increase in fertilizer application levels showed similar trend with that of plant height and number of leaves per plant. Plant biomass production was comparable between the fertilizer plots of S2 and S3 spacings. The sharp increase in biomass production from F0 towards F2 and the lesser increased between the F2 and F3 plots in S1, S2 and S3 spacing indicated that the affect of fertilizer on biomass production was more pronounced between F0 to F2 and further increase from F2 to F3 level had lesser impact on biomass production.

6.2 Effect of NPK fertilizer application on yield parameters

6.2.1 Length of cob

The length of cob which is a important yield parameter was significantly affected by fertilizer application showing wide range of less than15.00cm to greater than 19.00 cm in 2JC, 16.00cm to greater than 20.00cm in 3JC and, less than 18.00cm to greater than 22.00cm in 5JC among the spacing and fertilizer treatment. This implied the strong impact of space and nutrient availability on growth and the resultant biomass production of maize plant.

6.2.2 Kernel rows per cob

The number of kernel rows per cob is one of the important yield parameters than determine grain yield in maize. Although increasing trend of kernel rows per cob was observed from the F0 plot toward F3 plot in all the three spacing, there was only few significant difference. The inter jhum comparison also showed significant increase from 2JC toward 5JC in all the fertilizer plots of S1 but less significant variations in fertilizer plots of S2 and S3.

6.2.3 Kernels per row

Unlike kernel rows per cob, significant increase in the number of kernel from F0 toward F3 except in S2 spacing of 2JC indicated the strong impact of NPK fertilizer under different plant spacing. High rate of increased in number of kernels per row was observed from F0 toward F2 indicating the best response to NPK fertilizer by maize plant in the F1 and F2 application rate.

The highly significant increase in number of kernels per row 2JC to 5JC indicated the soil condition of longer jhum cycles might induced more kernels per row in maize. From the uniform increase in kernels per row from 2JC to 5JC, it is suggested that logner jhum cycles may induce further increase in number of kernels per row.

6.2.4 Kernels per cob

The similar pattern between length of cob and kernels per row of significant increase in with increase fertilizer levels as well as with the increase in jhum cycle resulted in the increase in total number of kernels per cob from plot without fertilizer application toward the highest level of fertilizer application as well as with the longer jhum cycles. Considering the overall range under different fertilizer application, spacing and jhum cycles, the wide range of the number of kernels per cob, it is evident that this was one of the most variable parameters and it could be crucial determinants of grain yield.

6.2.5 Test weight

The test weight was highly influenced by NPK fertilizer application under different spacing which indicated that NPK fertilizer induced the improvement of the quality of the kernel which manifested in the greater weight of 1000 seed grains. The significant increase in test weight from the 2JC to 5JC was also a strong determinant of grain yield of maize.

6.2.6 Grain yield/ha

The grain yield per hectare which was extrapolated from the yield per plant indicated the strong effect of fertilizer on grain yield of maize. Considering the increased in grain yield from the lowest yield in the highest density spacing (55cm x 20cm) without fertilizer application to the highest fertilizer application (120:60:40 kg/ha of NPK) with wider spacing (60cm x 25cm), the productivity of maize depend strongly on the cultural practice and selection of the most appropriate spacing and fertilizer input is the prerequisite. The strong influence of jhum cycles also indicated its impact of the yield of maize.

Although harvest index showed no significant variations among the fertilizer plots under different spacing, the significant difference among the jhum cycles indicated the grain yield per gram of biomass produced increases with increase in jhum cycles.

6.3 Effect of plant spacing on growth performance

6.3.1 Plant height

The effect of spacing on plant height increases with the progressed of the growth period and at 60DAS, spacing induced significant difference in plant height. This less significant variations at the early stage of growth was attributed to the sufficient space for plant at this stage. As the growth progressed more spatial competition in the high density spacing resulted in the reduction in plant height at S1 spacing of 55cm x 20cm that 90,909 plants per hectare. The S2 and S3 spacing of 75cm x 20cm (66,666 plants/ha) and 60cm x 25cm (66,666 plants/ha) showed comparable growth rates.

6.3.2 Number of leaves per plant

The effect spacing on the number of leaves per plant also increased with the increasing growth period with significant variations among the S1, S2 and S3 spacings in all the fertilizer application levels. Number of leaves was greatly reduced in highest plant density of S1 spacing.

6.3.3 Biomass production

Biomass production was strongly influenced by spacing with great reduction in plant dry biomass in S1 spacing. At high density planting, plants compete of vertical growth for better light inception which led to production of weak slender stalk in plants. The greater plant height and number of leaves felicitates high photosynthetic rates as well as larger photosynthetic area which improves further growth and development.

6.3.4 Effect of spacing on yield parameters

The S1, S2, and S3 had strong similar impact on length of cob, kernel rows per cob, kernels per row, kernels per cob and seed test weight which were the determinants of the grain yield. The S1 spacing of high density planting (90,909 plants/ha) considerable reduce the yield parameters.

The impact of spacing on grain yield was less significant when compared with that of the effect of fertilizer application.

The harvest index (HI) was strongly affected by spacing with low HI in the highest density plant of 55cm x 20cm. This implied that despite of the lowest biomass production in S1 spacing in each of fertilizer plots; the grain yield was proportionately lower which resulted in lower HI.

Chapter VI

SUMMARY AND CONCLUSION

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1. The study was carried out at the Edenthar locality which is at the outskirt of Aizawl city.
2. The jhum cycles viz. 2 years, 3 years and 5 years cycles were selected to study the extent of the influence of different jhum cycles on growth and productivity of maize.
3. Most promising local variety of maize called 'Mimpui" was selected as it has a high potential for commercial production of corn to meet various demands for human consumption as well as animal feeds.
4. Maize were grown under four levels of Nitrogen, phosphorus and potassium fertilizer treatments of 80N:40P:20K, 100N:50P:30K, 120N:60P:40K (NPK kg/ha) and Control (Without NPK) with combination of three different spacing of 75cm x 20 cm, 60 cm x 25 cm and 55cm x 20 cm.
5. Local maize variety grown under four levels of fertilizer treatments and two levels of spacing in three 2 years, 3 years and 5 years jhum cycles showed significant response in growth performance and yield characteristics
6. The variations in plant height and number of leaves per plant became more pronounced with the progress in growth period.
7. Fertilizer significant enhanced seedling vigor and plant growth.
8. Spacing also significantly affected plant growth which became more evident with increase in growth period as the competition for space and nutrient increases.

9. Highly density spacing of 55cm x 20 cm greatly reduce the growth and yield performance.
10. In most of the growth and yield parameters, lowest values were observed in plot with highest density and without fertilizer application where as plant spacing of 60cm x 25 cm showed maximum values in most of the parameters.
11. Jhum cycles significantly influenced growth performance in which poor growth was observed in shorter jhum cycle of 2 years when compared with 5 years jhum cycles.
12. Yield parameters were highly influenced by fertilizer application which increased with increase in fertilizer input.
13. Length of cob, number of kernels per row and test weight were the parameters which strongly influenced the grain yield.
14. Minimum grain yield of 6274.4 kg/ha occurred in highest plant spacing with no fertilizer application in 2 years jhum cycle.
15. Highest grain yield of 10549.9 kg/ha occurred in the 5 years jhum cycle with highest level of fertilizer application (120: 80 : 40 NPK per hectare)
16. From this experiment, it is evident that low soil nutrient under frequent jhum cycles is the major limiting factor for growth and yield of maize in the hilly slopes of Mizoram.
17. Considering the growth and yield under the three spacing, 60cm x 25cm is likely to be the most promising.

From this study, considering the overall effect of fertilizer, spacing and jhum cycles; the increased from the minimum values to the maximum values accounted for 43% in plant height at 60DAS, 26% in number of leaves at 60DAS, 47.79% in biomass per plant, 50% in length of cob, 28.15% in kernel rows per cob, 88% in kernels per cob, 21.83% in seed test weight, 68.14% in grain yield/ha, 54.58% in harvest index. This strongly indicated that optimization of cultural practice in in terms of spacing, fertilizer input and jhum cycles is needed for sustainable agriculture system even under jhum cultivation without compromising the yield of the Mimpui variety.

Maize is a nutrient demanding crop and due to its high uptake rate of available nitrogen, phosphorus and potassium from soil, fertilizer application in the successive cropping season may be prerequisite in similar jhum cycles to supplement the nutrient removal of the previous crop. Also due to the acidic condition of the soil, careful monitoring in application of acidic fertilizer like urea needed to be conducted to prevent setting up of unfavourable soil condition such as aluminium toxicity. From this experiment, it is observed that the Mimpui is a high yielding variety that could be promoted for commercial corn production. Considering the strong effect of NPK fertilizer in grain yield and at the same time the delicate soil condition under jhum cultivation, it is suggested that 5 years jhum cycle with lower rate of fertilizer application (80:40:20 NPK kg/ha) with spacing of 60cm x 25cm may be adopted.

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