CERTIFICATE

This is to certify that Ms. Lalnunthari has submitted the Ph.D Thesis entitled "**Study on Arbuscular Mycorrhizal Fungi (AMF) Communities from Jhum Lands in Mizoram, India**" under my supervision, for the requirement of the award of the Degree of Doctor of Philosophy in the Department of Environmental Science, Mizoram University, Aizawl. The work is authentic and the content of the thesis is the original work of the Research Scholar. The nature and presentation of the work are the first of its kind in Mizoram. It is further certified that no portion(s) or parts of the content of the thesis has been submitted for any degree in Mizoram University or any other University. She is allowed to submit the thesis for examination and for the award of the Doctor of Philosophy in Environmental Science.

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DECLARATION

I, Ms. Lalnunthari, hereby declare that the subject matter of this thesis entitled "**Study on Arbuscular Mycorrhizal Fungi (AMF) Communities from Jhum Lands in Mizoram, India**" is the record of the work done by me, and that the contents of this thesis did not form basis of award of any previous degree to me or to the best of my knowledge, to anybody else, and that the thesis has not been submitted by me for any research degree to any other University or Institute.

This is being submitted to the Mizoram University for the award of the Degree of Doctor of Philosophy in the Department of Environmental Science.

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CHAPTER 1

General Introduction

1 Introduction

A mycorrhiza is a symbiotic association between a fungus and the roots of a vascular plant. Mycorrhiza is a composite structure comprising fungus and higher plants roots. This term was given by a German forest pathologist, Albert Bernhard Frank in 1885.

In a mycorrhizal association, the fungus colonizes the host plant's roots, either intracellularly as in arbuscular mycorrhizal fungi (AMF or AM), or extracellularly as in ectomycorrhizal fungi. They are an important component of soil life and soil chemistry.

Mycorrhizas form a mutualistic relationship with the roots of most plant species. While only a small proportion of all species has been examined, Trappe (1987) reported that 95% of those plant families are predominantly mycorrhizal while Smith and Read (2008) reported 97% of terrestrial plants formed symbiosis with AM fungi. In the meantime, Wang and Qiu, 2006 suggested that Arbuscular mycorrhizas are found in 85% of all plant families, and occur in many crop species. They are named after their presence in the plant's rhizosphere (root system). This mutualistic association provides the fungus with relatively constant and direct access to important soil nutrients, carbohydrates, such as glucose and sucrose (Harrison, 2005).

Mycorrhizal fungi are known to form symbiosis in roots of the majority of higher plants. These associations differ widely in structure and functions, but the most common interactionis the arbuscular mycorrhizal (AM) association. These include of many agriculturally and horticulturally important crop species (Smith and Read, 1997).

The carbohydrates are translocated from their source (usually leaves) to root tissue and on to the plant's fungal partners, the plant gains the benefits of the mycelium's higher absorptive capacity for water and mineral nutrients due to the

comparatively large surface area of mycelium: root ratio, thus improving the plant's mineral absorption capabilities in return (Selosse *et al.,* 2006).

Mycorrhizas are commonly divided into *endo-mycorrhizas* and *ecto-mycorrhizas*. These two types are differentiated by the fact that the hyphae of endo-mycorrhizal fungi penetrate the cell wall and invaginate the cell membrane while the hyphae of ecto-mycorrhizal fungi do not penetrate individual cells within the root.

Endomycorrhizas are variable and have been further classified as arbuscular, ericoid, arbutoid, monotropoid, and orchid mycorrhizas (Peterson *et al.,* 2004). Arbuscular mycorrhizas, or AM (formerly known as vesicular-arbuscular mycorrhizas, or VAM), are mycorrhizas whose hyphae enter into the plant cells, producing structures that are either balloon-like called vesicles or dichotomously branching invaginations known as arbuscules. The fungal hyphae do not penetrate the protoplast of the cell but invaginate the cell membrane. The structure of the arbuscules highly increases the contact surface area between the hypha and the cell cytoplasm to facilitate the transfer of nutrients between them.

Ectomycorrhizas, or EcM, are generally formed between the roots of around 10% of plant families, mostly woody plants including the birch, dipterocarp, eucalyptus, oak, pine, and rose families, orchids, and fungi that are belonging to the Basidiomycota, Ascomycota, and Zygomycota. Some EcM fungi, such as many *Leccinum* and *Suillus*, formed symbiosis with only one particular genus of plant, while other fungi, such as the *Amanita*, are generalists that form mycorrhizas with many different plants (den Bakker *et al.,* 2004). An individual tree may have 15 or more different fungal EcM partners at one time (Saari *et al.,* 2005). Thousands of ectomycorrhizal fungal species exist and hosted in over 200 genera.

The AM fungi are the most complex group of mycorrhizas which forms inter-radical structures: (1) intracellular hyphae forming coils that are often found in the outer layers of cortical parenchyma, (2) the intercellular hyphae, (3) the intracellular hyphae withnumerous ramifications, i.e. the arbuscules, and (4) the inter- or intracellular hypertrophied hyphae, i.e. the vesicles. Arbuscules are the vital sites for nutrient exchange and remain active only for 4–15 days (Carling and Brown, 1982;

Cox and Tinker, 1976). Many endomycorrhizal fungi which form arbuscules soon form terminal or intercalary vesicles in the root cortex. These are expanded; thin-walled structures often contain a large quantity of lipids which are not delimited by a septum called as vesicles. They may be spherical, oval or lobed and may become thick-walled and resemble resting spores. They behave as the endophytic storage organs and are rich in lipids.

Arbuscular mycorrhizas are formed only by fungi in the phylum of Glomeromycota. They are the most ancient, abundant, and ecologically important plant-fungal symbiosis on Earth (Parniske, 2008; Smith and Read, 2008). Despite their pronounce keystone role in terrestrial ecosystems, ecological studies of AMF (SchuBler *et al,* 2001; van der Heijden and Sanders, 2002) have generally been hampered by their obligate biotrophic lifestyle and complex genetics (Sanders, 2002; Smith and Read, 2008).Fossil evidence (Remy *et al.,* 1994) and DNA sequence analysis (Simon *et al.,* 1993) suggest that this mutualism appeared between 400-460 million years ago, when the first plants were colonizing land. The hyphae of arbuscular mycorrhizal fungi may be one of the major stores of carbon in the soil because they produce the glycoprotein glomalin. Arbuscular mycorrhizal fungi may have (possibly) been asexual for millions of years and, unusually, individuals can contain many genetically different nuclei (a phenomenon called heterokaryosis) (Hijri and Sanders, 2005).

ArbuscularMycorrhizal Fungi in Cowpea

Cowpea is a multipurpose legume crop that serves as human food, livestock fodder, and income source and is widely produced in Mizoram, India. They are also an economically important staple food crop in many semiarid regions of the tropics and subtropics, grown mainly by subsistence farmers under low input of agrochemicals or irrigation water (Timko and Singh, 2008). Cowpea being a protein-rich grain is a suitable complement to starchy tuber crops and staple cereals. It serves as livestock fodder, improves the soil via nitrogen fixation, and benefits households by bringing in cash and diversifying income sources. Vital household income is also

generated through the sale of cowpea leaves and stems for animal feed during the dry season. Soil fertility and attack by insect pests and diseases are significant limitations to its production. There is at least one major insect pest at every stage of cowpea's life cycle, which could cause serious damage and negatively impact the yield (Gomathinayagam *et al*., 1998). Most farmers rely on costly commercial farm inputs such as insecticides and phosphate-rich fertilizers to reduce the mentioned constraints. These types of fertilizers are not costly but also harmful for human being. There is the need to come up with alternatives environment friendly for minimizing over-reliance on such commercial farm inputs. Host-plant resistance is the most economical and environmentally friendly way of controlling insect pests (Sharma and Ortiz, 2002). Plant growth is affected by low phosphorous availability in many soils as a result of P fixation by Fe, Ca and Al, which leads to formation of inorganic phosphates that are insoluble in soil (Ibijbijen *et al*., 1996). However, AMF have been found to increase nodulation and atmospheric nitrogen fixation potential in legumes such as cowpea (Turk *et al*., 2008). This is because AMF improves phosphorous uptake by the plant, which in turn would avail more energy for nitrogen fixation by rhizobia. Mycorrhizal colonized roots are highly unlikely to be colonized by other microbes, and their susceptibility to soil-borne pathogens such as phytopathogenic fungi or nematodes is lowered (Selveraj and Chellappan, 2006). Arbuscular mycorhizal fungi are one of the important beneficial microorganisms in the rhizosphere. This symbiotic association offers a viable replacement for the high input agricultural technology employed for the use of expansion and often environmentally hazardous fertilizers.Crop plants may benefit from the mycorrhizal association because of greater efficiency in nutrient and water uptake from soil (Mosse, 1981; Lakshama, 1992; Kunwar *et al*., 1999).

ArbuscularMycorrhizal Fungi in Maize

Maize is widely cultivated throughout the world. It has become a staple food in many parts of the world including Mizoram, with the total production of maize surpassing that of wheat or rice. Its economic and nutritional value is mainly due to the high starch content that represents about 75% of mature seed weight (Raquejo

and Tena, 2006). Maize (*Zea mays* L.) originates from the subtropical regions and is known to be sensitive to low temperature stress. Low temperature adversely affects seed germination and overall growth and productivity of maize plants (Jones *et al*., 2009). Maize is strongly dependent on mycorrhizae (Mechin *et al*., 2007). Bona *et al*., (2016) reported the enhancement of spike dry weight, spike length, spike circumference and the dry weight and dimensions of the grain in maize due to AM symbiosis. The AM symbiosis, formed between the roots of most terrestrial plants (Smith and Read 2008; Zhu *et al*., 2010) and fungi of the phylum Glomeromycota, reduces environmental stress to the host plant (Baumann *et al.,* 2005) through multiple benefits, including enhanced water and mineral nutrition absorption and tolerance to different environmental stress factors (Smith and Read, 2008). AMF association stimulates plant growth in soils and substrates with lower fertility through improving nutrient (phosphorous) uptake in host plants (Smith and Read, 2008) and enhancing plant tolerance to various abiotic stresses, including high or low temperature (Miransari*et al*., 2008; Zhu *et al.,* 2010), drought (Augé, 2001), salinity, (Ben Khaled*et al.,* 2003), etc.

ArbuscularMycorrhizal Fungi in Banana

Banana is a food crop produce widely around the world and is considered one of the most important food crop worldwide with an annual production of 102 million tonnes (FAO, 2005) due to its high nutrient content and commercial values. It is the fourth most important global food commodity after rice, wheat and maize in terms of gross value production (CGIAR, 1993). It is the staple food for nearly 400 million people worldwide. Wild and cultivated bananas are abundantly available in Mizoram, which is one of the states of Northeast Indian region.The climatic condition seems very suitable for this species and had been consumed by most of the people in Mizoram. Due to several factors, there is a rapid loss of this food crop in Mizoram (P.C.Lalrinfela and Robert Thangjam, 2012).Banana is a monocotyledonous herbaceous species that shows a great ability to establish mycorrhizal symbiosis (Jaizme-Vega *et al*., 2002). Mycorrhizae fungi are perhaps the most abundant fungi in agricultural soils, which accounts for 5–36% of the total biomass in soil and 9– 55% of the biomass of soil

microorganisms (Olson *et al*., 1999). AMF association may stimulate plant growth in soils and substrates with lower fertility through improving nutrient (phosphorous) uptake in host plants (Smith and Read, 2008). Banana and plantain cultivars are naturally colonized by arbuscular mycorrhiza fungi. AMF are reported to be an important part of sustainable agricultural systems that have low inputs of chemical fertilizers and biocides (Bethlenfalvay and Schüepp, 1994; Jeffries and Barea, 1994; Hooker and Black, 1995). Number of studies reported on the protective effects of AMF on banana against nematodes (Declerck*et al*., 1994; Gera Hol and Cook, 2005). The importance of mycorrhizal fungi in the relationship between biodiversity and ecosystem functioning is now being recognized, particularly with respect to their potential to control plant diversity and productivity (van der Heijden *et al*., 1998a). During the last two decades, arbuscular mycorrhizal fungi have been known as a valuable microbiological resource in crop production. Much work has been done on VAM in temperate countries and research on VAM has also made significant advancement in tropical countries (Bagyaraj *et al*., 1979; Bagyaraj, 1984). Banana roots were simultaneously colonized by AMF throughout its life cycle and this help the plant to survive from extreme climatic condition. Shifting plantation (slash-and-burn) does not affect AMF communities (Aguilar-Fernández *et al*., 2009).

Several biotic and abiotic factors such as seasonal changes may interact to manage the structure of mycorrhizal fungal communities above ground plant community, through specificity or preference exhibited by either partner in the mycorrhizal symbiosis (Shi *et al.,* 2006; Verma *et al.,* 2008; Kivlin *et al.,* 2011; Shukla *et al.,*2013). When soil conditions are altered by any changes in the environment, the number of organism's changes and the relative abundance of different types of organisms in the soil changes as well. A change in environment may favour one group of organisms so that its abundance increases, while the number of other organisms decreases either because the conditions are less favourable or because of the increased influence the organisms that have become dominant (Russell, 1973).

Shifting Cultivation and ArbuscularMycorrhizal fungi

Shifting cultivation is one of the main forms of crop husbandry in Mizoram and other North Eastern Region of India and is commonly known as jhuming. This system often involves clearing a piece of land by slashing and burning of woods followed by wood harvesting or farming. Once the land becomes unproductive, it is left to be reclaimed by regeneration of natural vegetation, or sometimes converted to different long-term cyclical farming practices. However, this type of farming is the root cause of soil degradation. The restoration of jhum fallows were not all successful in many regions due to lack of knowledge about the important processes that takes place inside the soil particles. Since the jhum fallow site was cleared and uncontrolled burning was done for every time prior to cropping, the continuity of the life cycle of AM fungi must have been affected by removal of the host plants. When a soil is put to agricultural use it undergoes a series of physical, chemical and microbiological changes. One of the most important of which is the changes that affect the root-inhabiting microorganisms and poor plant growth (Bellgard, 1994; Roldan *et al.,* 1997).The results of any interactions between AM fungi will influence the ecological balance within the soil/root matrix. Since these fungi are important as pioneer colonizers (Forster and Nicolson, 1981), as established residents of cultivated soils (Abbott and Robson, 1982b), and for maximum growth of plants in treated sterilized soils (Menge *et al*., 1977), their activities are of special interest to both soil conservationists and agriculturalists. The mycorrhizal fungi are known to play important role in the regeneration of the abandoned forests due to their symbiotic association with plant roots (Singh *et al*., 2003). Miller (1979) also reported that when soil is disturbed or is partially removed, a decrease in the number of mycorrhizal propagules occurs.

Diversity of AMF species seems to be essential for sustainable functioning of the ecosystem in the event of sudden changes in environmental conditions (Wang *et al*., 1985, Abbott and Gazey, 1994). Agricultural practices may induce selection pressure in such a way that a certain AMF group could adapt to changes, establish and proliferate better than others (Singh *et al*., 2008). The occurrence of many AM species in a diversity probably related to their edaphic requirements. Several edaphic

factors such as pH, soil texture, organic matter, soil moisture and nutrient level were shown to affect spore germination, root colonization and efficiency of AM fungi (Khalil *et al*., 1992). Distribution and diversity of AM fungi in different species of a particular agro-ecological zone are important in order to evaluate the natural status of AM fungi in that region. The beneficial influence of indigenous AM fungi is most important in stressed environment and circumstances. It is widely accepted that climatic and edaphic factors can substantially influence AM fungi and their populations, rapid changes in the soil nutrients may affect AM association and spore number (Abbott and Robson, 1991). Mycorrhizal fungi also change in predictable successional patterns, along with plant species and soil nutrient status. The species occurring at a particular successional stage may therefore be those best able to acquire and transport nutrients under the current condition (Gorham *et al*., 1979; Last *et al*., 1987; Read, 1993). Usually, plant, soil and climatic factors are related to the development of these fungi, and show varied effects on establishment of the mycorrhizal symbiosis and its efficiency (Carrenho*et al*., 2007).

Arbuscular mycorhizal fungi are considered to be one of the most important beneficial microorganisms in the rhizosphere. To date, there is no systematic report of AMF association in Mizoram. There is also no record on study of AMF association or communities in different ages of jhum lands globally. Therefore, considering the lack of systematic studies on AMF association in Mizoram and AMF association in different ages of jhum lands globally, the present study was carried out in order to generate the baseline data on taxonomy and diversity of AMF in Mizoram.

1.2OBJECTIVES OF RESEARCH

This research undertakes the following objectives:

1. Taxonomical study of ArbuscularMycorrhizalFungi species.
2. To study association of ArbuscularMycorrhizal Fungi with the selected plants.
3. To study the diversity of ArbuscularMycorrhizalFungal communities in the selected sites.
4. To study the physico-chemical characteristics of the soil in the selected sites.

CHAPTER 2

Review of Literature

Arbuscular mycorrhizal (AM) fungi are recognized as common type of mycorrhizae with diverse host range (Gerdemann, 1968; Jagpal and Mukerji, 1988, 1991). VAM fungi have a wide range of hosts because these fungi are not host specific. Endo-mycorrhizal infection is non-pathogenic and produces very little or no change in the physical appearance of the roots. These vesicular arbuscular mycorrhizas are prevalent and found in almost all the angiospermic families except some families such as Betulaceae, Commelinaceae, Urticaceae etc. (Gerdemann, 1975). Families that rarely form mycorrhizae are Brassicaceae, Chenopodiaceae, Cyperaceae, Polygonaceae (Gerdamann, 1975; Tester *et al*., 1987; Meney*et al*., 1993; Gupta and Mukerji, 1996). They are physiologically obligate biotrophs and do not grow on synthetic media (Azcon-Aguilar and Barea, 1992).

Vesicular arbuscular mycorrhizae are the most abundant with widest host range and geographic ubiquity (Mukerji and Mandeep, 1998; Wolfe and Klinomus 2005; Smith and Read 2008; Lee *et al.,* 2013). VAM fungi are found associated with plant roots of arctic, temperate and tropical regions and are distributed in nearly all the families of angiosperms (Kendrick and Berch, 1985; Schuβler and Walker, 2010). VAM fungal propagules have been isolated from forest, open woodlands scrub, savanna, heath, grasslands, sand dunes, semi-desert and bituminous coal wastes (Pflege*et al*., 1994; Cuenca *et al*., 1998; Delvian, 2003; Puspitasari, 2005). Many species of plants of economically important families have been reported to be mycorrhizal (Sutton, 1973; Bird *et al*., 1974; Hayman, 1975).

It is known that VAM fungi play a dominant role in providing unavailable resources of plants and increase phosphorus solubilization and greater supply of P, N, Ca, S, K, Mg, Mn and modifying soil fertility to support plant development and nutrient. Crop plants may benefit from the mycorrhizal association because of greater efficiency in nutrient and water uptake from soil (Kunwar *et al*., 1999; Smith and Read, 2008).

Mycorrhizal fungi are benefited with carbon substrates from plants and in turn the plants are provided with nutrients especially phosphorous compounds from soil solution through the hyphal network of the fungi apart from increased absorptive surface area of the roots (Loyanachan, 2000; Ravarkar *et al.,* 2000).

Arbuscular mycorrhizal associations are widespread among agricultural and horticultural crop plants (Abbott and Gazey 1994; Smith and Read, 2008), although their impacts on those systems under field conditions can be highly variable and, thus, not always definitive (Jeffries and Dodd, 1991). They play an important role in P uptake and growth and development of many cereals, legumes, and other crop plants (Sieverding, 1990; George *et al*., 1995). The AMF association may also increase the tolerance of host plant against biotic (Hol and Cook 2005; Akhtar and Siddiqui 2007) and abiotic stresses, including salinity and drought (Cartmill*et al*., 2007).

In temperate regions, EM fungi improve significantly the growth and mineral nutrition of trees (Smith and Read, 2008). They also allow the trees to better withstand some root diseases and exploit the water resources. Arbuscular mycorrhizal fungi are able to colonize and establish symbiotic mutually beneficial associations with roots of most agricultural crops (Munyanziza *etal*., 1997) and increase the effective absorptive area of roots by the formation of an extensive extraradical hyphal network that enhances efficiency in absorption of nutrients (George, 2000). The importance of AMF in improving plant growth and plant resistance to soil borne diseases and restoring problematic soils is well known (Jeffries *et al*., 2003; Rillig, 2004; Aimir *et al*., 2008). Plant response to arbuscular mycorrhiza (AM) is extremely variable, both among species and within species (Koide, 1991).

Tropical countries regularly encounter many edapho-climatic constrains that limit crop production. Low fertility is one of the important and major factors responsible for low crop productivity. Mycorrhizal symbiosis plays an important role in the tropical agricultural crops because in tropical region the soil is phosphorus deficient. Mosse (1973) reported that 73 per cent of the phosphorus applied to the crops is not utilized by them but converted to forms unavailable to plants.

Currently, about 250 species of AMF are described in the world (Jansa *et al*., 2014). These symbiotic microorganisms have been formerly identified by the morphological characteristics of their spores although sporulation is under the control of several parameters such as environment, seasonal variation, host plant, genotype and AMF species (Sanders, 2004; Smith and Read, 2008). Thus, spore counting and identification based on morphological characterization do not effectively reflect the diversity of active AMF communities in plant roots (Schüßler *et al*., 2001)

The traditional procedure to survey the presence of AMF in ecosystems relies on extraction of spores from soil bywet sieving techniques and taxonomic classification basedon spore morphology. A wide range of AM Fungi distribution isfound in India. Bakshi (1974) was the firstto give an account of 14 spore types: *Glomus macrocarpum Tul and Tul var., G.geosporum, G.mosseae, Glomus sp., Sclerocystis coremioides*, *Sclerocystis sp., Gigaspora, Calospora, Acaulospora sp., Endogone gigantea, E. Microcarpum, Endogone 1, Endogone 2, Endogone3*. Gerdemann and Bakshi (1976) reported two new species viz., *Glomus multicaule* and *Sclerocystis sinuosa*. Zhang *et al.* (2004) surveyed 44 taxa of AM fungi of AM fungi (total species richness) in the deforested and natural forest in sub-tropical region of Dujiangyan. They also reported that *Acaulospora* and *Glomus* were the dominant genera in the study sites.

Muthukumar and Udaiyan (2000) surveyed the arbuscular mycorrhizal (AM) status of plants growing in Western Ghats region of Southern India. They recorded 174 species from 329 plant species where 35 species belonging to *Acaulospora, Gigaspora, Glomus, Sclerocystis and Scutellospora.* The Vesicular Arbuscular Mycorrhizal status was examined in Pteridophytes of Western Ghats of Southern India by Muthukumar and Udaiyan (2000). According to them, sixty of the seventy one species of Pteridophytes showed VAM association and the substratum strongly influenced the presence of mycotrophy. Rodrigues and Jaiswal (2001) recorded AM association in six plant species growing on sand dune vegetation of Goa. They reported the presence of three AM fungal genera viz., *Acaulospora*, *Glomus* and *Sclerocystis*. Reddy *et al*., (2006) reported fifteen AM fungi in the rhizosphere soil of

three solanaceous vegetable namely, tomato, chilli and brinjal collected from five different locations. The genus *Glomus* is the most dominant fungus followed by *Acaulospora, Sclerocystis, Gigaspora* and *Entrophospora*. Sixteen AMF morphotypes were identified from the potato field in Meghalaya belonging to genera *Acaulospora, Gigaspora, Glomus, Pacispora* and *Scutellospora;* a few remain unidentified with the dominance of *Glomus tortuosum,Pacispora bolivianaand Gi. Margarita* from Meghalaya, Northeast India (Das and Kayang, 2010).

Ruhling and Tyler (1990) reported that soil base saturation and organic matter content as the most important factors governing the distribution of both mycorrhizal and non mycorrhizal macrofungi in Swedish deciduous forests.Opik *et al*, (2006) suggested that AM fungal distribution in these forests, although obviously tied to host plant distributions, may be further influenced by edaphic factors. Kernaghan and Harper (2001) observed a similar trend in the relationship between host plant diversity and EM diversity with increasing elevation across tree line in the Canadian Rockies. The distribution of AM sporesin rhizosphere soil is governed by edaphic and certain climatic factors. According to Khaliel (1988), pH is the only edaphic factor which determines the abundance of AM fungi. In contrast to that, Bergan and Koske (1981) suggested that pH did not influence the mycorrhizal spore density and frequency.

Arbuscular Mycorrhizal Fungi in Cowpea

Grain legumes like cowpea depend on rhizobia for nitrogen supply (Mulongoy, 1985) and AMF essentially benefits plant by improving its mineral nutrition, water uptake and hormone production (Marschnen and Dell, 1994). The AMF associations are reported to be involved in N transfer from legume to cereal in intercropping systems (Makoi and Ndakidemi, 2009). It is well established that the association of legumes with arbuscular mycorrhizal fungi (AMF) can increase hydro mineral nutrition and significantly reducing parasitic infection and therefore allows to increase their productivity even when these plants grow on soils relatively poor (Hadiarto and Tran, 2011; Rooney *et al*., 2011; Zhao *et al*.,

2015; Frosi *et al*., 2016; Yooyongwech *et al*., 2016). Xavier and Germida (2003) reported that a rapid root colonization by an efficient AMF isolates will allow the cowpea to increase its total absorption surface and uptake P that are far away from the root zone under limiting P conditions soils in southern Cameroon where farmers usually do not apply inorganic fertilisers to their crops. The AMF can increase growth in cowpea was reported by Hadou *et al*. (2016)**.** Increasing cowpea productivity by combining rock phosphate and arbuscular mycorrhizal fungi in the Sub-Saharan region of Africa was reported by Suzuki *et al*. (2017). AMF in cowpea can improve plant growth under low soil fertility condition, confer tolerance to some pathogens, improve the water balance of plants and can influence soil aggregation(Dalpé, 2005; Marulanda *et al*., 2006; Rillig and Mummey, 2006). Spore population gradually increase in the rhizosphere of cowpea in both saline and non-saline soil was reported by Yamato *et al*. (2008) while Sheng *et al*. (2008) suggested that soil salinity directly affect the fungal development, reducing fungal mycelia formation and host root colonization. The interaction of plant nutrients, root-soluble carbohydrate availability and AMF examined in field grown cowpea *(Vigna unguiculata)* revealed that organic amendments increased plant growth, AMF fungal colonization, soluble carbohydrate concentration inroots, and spore numbers (Muthukumar and Udaiyan, 2002b). Seven genera viz., *Glomus, Scutellospora, Gigaspora, Entrophospora, Acaulospora, Sclerocystis* and *Rhizophagus* was reported from two ecological sites in Senegal (Diop *et al*., 2015). Sixty-four AMF species were recorded in cowpea, with predominance of *Glomeraceae* and *Acaulosporaceae* in Brazil Caatinga and experimental agroecosystem (de Pontes *et al*., 2017). They also reported the effect of jhum fallows in the diversity and sporulation. Johnson *et al*.(2013) reported the detection of 15 AMF morpho-species belonging to eight genera viz., *Gigaspora, Scutellospora, Racocetra, Acaulospora, Funneliformis, Rhizophagus, Glomus* and *Claroideoglomus* from the rhizosphere of cowpea in Benin, West Africa.

Arbuscular Mycorrhizal Fungi in Maize

The symbiotic association between Arbuscularmycorrhizal fungi (AMF) and roots of plants are known to improve the nutritional status, growth and development of plants, protect plants against root pathogens and also offer resistance to drought and salinity (Jeffries 1987). The significant effect on maize growth by AMF was reported by Aguegue (2017). A better growth of the corn seeds inoculated with an indigenous arbuscular mycorrhizal fungi compare with control plants was observed in water stress conditions by Subramanian *et al*. (1995). Moreover, Usharani *et al*. (2014) showed the significant positive effect of the kind *Glomus* (*G. fasciculatum*) on the corn growth (+32.67%) in India. Augé *et al*. (2004) explained the growth improvement by a better water absorption, while Yamawaki *et al*. (2013) and Sharma *et al*. (2016) explain it by a better absorption of mineral manures. AM fungi are among the most common soil fungi (Gerdemann, 1963) associated with the roots of the majority of land plants in a variety of natural and agricultural ecosystems (Tao and Zhiwei, 2005), including arid and semiarid areas (Carrillo-Garcia *et al.*, 1999). They play a fundamental role in soil fertility and in the maintenance of stability and biodiversity within plant communities (Giovannetti and Avio, 2002). AMF colonization is known to have a positive effect on plant growth, but the physico-chemical state of the soil could directly impact the symbiotic relationship between the plant and fungus (van der Heijden *et al*., 1998a). Improvement of growth in maize especially in water stress condition was reported by Benjelloun *et al.* (2014). Phosphorus is required in large amounts by plants and its availability may limit plant growth (Bayuelo-Jiménez *et al*., 2011). Maize crops stood out for demanding high amounts of fertilizers, mainly phosphates, and for being responsive to AMF (Thompson *et al.*, 2012). A significant variation in root colonization was also found in maize in a relay cropping system due to different P level in soil (Shrestha *et al*., 2009). The enhancement in the uptake of phosphorous and nitrogen in maize was reported by Kessel *et al*. (1985).Bordoloi *et al*. (2015) reported about the effect on the distribution of mycorrhizal fungi in different landuse systems.Jansa *et al*. (2003) in a long-term field experiment under different soil tillage practices in Switzerland, found changes in community of AMF colonizing maize roots, and concluded that

changes in community of AMF might be due to the differences in tolerance to the tillage-induced disruption of the hyphae among the different AMF species, changes in nutrient content of the soil and microbial activity.

AM fungi are reported to reduce the detrimental effects of soil-associated plant stresses, such as lack of nutrients, organic matter, high salinity or high pH (Sylvia and Williams 1992; Entry *et al*., 2002). The high amount of hyphae produced by AMF is correlated with significant increases in the aggregate stability of soils (Tisdall *et al*., 1997; Jastrow *et al*., 1998; Rillig, 2004a; Treseder and Turner, 2007), modifying the soil's ability to mobilize nutrients, water content, as well as root penetration in soil and soil erosion potential. In this sense, mycorrhizal networks can create indefinitely large numbers of fungal linkages connecting together many plants in a community (Newman, 1988). Oehl *et al*. (2003) while studying the impact of land use types reported that the AMF species composition was the highest in grasslands, lower in the low and moderate input arable lands and the lowest in the lands with intensive continuous maize mono-cropping. AM fungi are able to increase the absorption area in maize roots through increasing the number of membrane cells was reported by Taylor *et al*. (2008). Muller and Hofner (1991) reported that inoculation of *Glomus etunicatum* in maize plants, under water stressed conditions, absorbed more phosphorus than non-mycorrhizal plants in sandy loam soil.Castelli *et al*. (2014) reported three AMF genera, *Glomus spp., Gigaspora spp*. and *Acaulospora spp* from North-western region of Paraná state, Brazil under different soil management and seed treatment with fungicides.Suchitra *et al*. (2012) observed *Glomus spp., Gigaspora spp., Acaulospora spp,* and *Scutellospora sp* in the sub-tropical soil of Coimbatore, Tamil Nadu out of which *Glomus mosseae* were found to be dominant.

Arbuscular Mycorrhizal Fungi in Banana

Banana production mainly depends on the plants' root growth and development for efficient water and nutrient uptake. Soil constraints such as water stress, mechanical impedance, soil acidity, and the activity of soil-borne pests and

pathogens can reduce plant uptake of such essential substances (Aggangan *et al*., 2013). Biodiversity of arbuscular mycorrhizal fungi (AMF) in banana plantations in india by Sumathi and Thangavelu (2016) reported that AMF association benefit the banana plants by increasing growth, nutrient uptake and defence mechanisms by the influence of AM fungi. Salinity reduced mycorrhizal root colonisation, but did not influence the density of the AMF spores (Almeida *et al*., 2016). Bananas are dependent on mycorrhizas hence their inoculation at the hardening stage may improve banana adaptation in harsh environments resulting in increased banana production hence poverty alleviation (Mwashasha *et al*., 2011). Growth promotion of micropropagated banana due to inoculation with mycorrhizal fungi was reported by Jaizme-Vega *et al*., (1997) and Pinochet *et al*., (1996). Effect of AM fungi and rhizobacteria on banana growth and nutrition in Spain by Rodríguez-Romero *et al*. (2005) showed that the interaction between *Glomus manihotis* and *Bacillus spp*. improved plant growth and mineral uptake of micropropagated banana plantlets. Emara *et al.* (2018) on role of Mycorrhiza as biofertilization of Banana Grand Naine on Inoculation banana cultivar Grande Naine in Egypt reported that with various doses of AM fungi during nursery stage improved vegetative growth parameters, number of leaves, leaf area, plant height, pseudostem length, fresh and dry weight.

AMF colonization induces systemic resistance of the plant towards plant parasitic nematodes rather than through direct competition or inhibition in *Musa sp*, (Elsen *et al*., 2008). Plant parasitic nematodes are amongst the most common pest constraints to banana production (Gowen *et al*. 2005). Colonization of plant roots by AMF has been shown to reduce damage by soil-borne plant pathogens such as nematodes. A study on AM fungi and nitrogen fixing bacteria as growth promoters and as biological control agents against nematodes in tissue-cultured banana var. lakatann in Phillipines by Aggangan *et al*. (2013) suggested that mycorrhiza alone is the best treatment in promoting the growth of banana var Lakatan seedlings and effective bio-control agent in controlling nematode population and infestation. . Fernándes *et al*. (2003) have shown that colonization by *Glomus intraradices, G. Manihotis* and *G. mosseae* reduced nematode damage caused by *R. Similis* and *M. incognita* on banana in pots in Cuba.

For a species to occur in diverse habitats, it must have physiological and genetic characteristics which enable the species to survive different environmental conditions (Heslop- Harrison, 1964). Even though AMF are sensitive to environment (Mosse *et al.,* 1981), some individual species are very widely distributed and can tolerate different environmental conditions (Stahl and Christensen, 1982). The spatial and temporal distribution of the AMF community in a wet tropical rainforest in Costa Rica was examined. AMF communities are spatially distinguishable in the forest, even though all species are widespread. Sampling soils over seasons revealed that some AMF species sporulate profusely in the dry season compared to the rainy season (Lovelock *et al,* 2003).

Sumathi and Thangavelu (2016) reported the presence of three different genera *viz*., *Glomus* (7 species), *Acaulospora* (2 species) and *Scutellospora* (2 species) in banana plantation in Tamil Nadu. Bever *et al*. (1996) identified 10 species of AMF belonged to the genera of *Acaulostis* (9 species) and *Scutellospora* (1 species) in which *Acaulospora* and *Glomus* were the dominant genera and *A. denticulata*, *A. foveata*, *A. spinosa*, *A. tuberculata*, *G. claroidenum*, *G. clarum*, *G. Constricum* and *G. Monosporum* were the dominant species in the tropical rainforest of Xishuanogbanna in China. Victor *et al*. (2014) reported 23 AMF morphospecies belonging to four genera out of which 11 corresponded to *Glomus*, 10 *Acaulospora*, one to *Gigaspora* and one to *Ambispora*. The variation in the occurrence of different genera and species of AM fungi with banana cultivars might be due to variations in soil chemical characteristics. Root colonization and plant mycorrhizal dependency may be genotype and environment dependent traits (Smith and Read, 1997).

Shifting Cultivation and AMF

Because AMF propagate only in the presence of plants, their diversity and function respond rapidly to changes induced by soil disturbance, nutrient management and crop diversification (Douds and Millner, 1999; Jansa *et al*., 2002; Gosling *et al*., 2005). The overall effect of AMF symbiosis varies from positive, neutral or negative depending on the identity of fungus, plant host and the

environmental context such as nutrient availability and agricultural practices (Bever, 2002; Klironomos, 2003; Reynolds *et al*., 2005; Reynolds *et al.,* 2006; Hoeksema *et al*., 2010). AM fungi vary in their effectiveness with change in soil conditions. Irrigation with effluents or natural soil pollutants may interfere with the possible benefits of mycorrhizal association on plant nutrition and health because, AM fungi formation and functioning depends mainly on the edaphic factors like soil moisture, pH and fertility (Hayman, 1982). AMF are among the most important biological factors influencing soil structure (Jastrow *et al*., 1998; Rillig *et al*., 2002; Rillig and Mummey, 2006). Effects of available P on AMF may vary depending on the availability of other nutrients in the soil. A high concentrations of N with low P increased AMF colonization and external hyphal growth while high P concentration accompanied with high concentrations of the other nutrients (N) depresses AMF colonization and hyphal growth (Liu *et al*., 2000; Valentine *et al*., 2001). During the last two decades, AM fungi have been identified as a valuable microbiological resource in crop production. Much work has been done on AM Fungi in temperate countries and research on AM fungi has also made significant strides in tropical countries (Bagyaraj*et al*., 1979; Bagyaraj, 1984).The impact of land use intensity on the diversity of AMF was investigated at eightsites in the "three-country corner" of France, Germany, and Switzerland. The increased land use intensity was correlated with a decrease in AMF species richness and with a preferential selection of species that colonized roots slowly but formed spores rapidly (Oehl *et al.,* 2003). Oehl *et al*. (2010) who studied 16 sites differing in agricultural land use intensity in Central Europe, concluded that land use intensity and soil type strongly affected AMF community composition, as well as the presence and prevalence of many AM fungi. Slash and burn practices on soil chemistry caused a surge in plant available nutrients and decline in AM fungi in soil and in *Didierea madagascariensis* from dry tropical forest of Madagascar was reported by Barraclough and Olsson (2018). Vieira *et al*. (2020) also reported that the distribution of AM fungi was determined by soil properties.

There is significant evidence pointing to the importance of soil conditions in the control of mycorrhizal fungal communities (Bruns, 1995; Erland and Taylor,

2002). There have been large reports on the nature of redistribution and diversity of mycorrhizal fungi in the disturbed soil environments. Singh *et al*. (2003) reported a significant decrease in propagule populations, species abundance and diversity of VAM fungi in the jhum fallow site even after five years of regeneration period as fallow land after slash-and-burn agriculture in comparison to natural forest site. Mycorrhizal plants are often more resistant to diseases, such as those caused by microbial soil-borne pathogens, and are also more resistant to the effects of drought (Lehto, 1992; Nikolaou *et al*., 2003). It plays a key role in the biology and ecology of forest trees, affecting growth, water and nutrient absorption and protection against pathogens. Mycorrhizas are the most widespread symbiosis in forest and cultivated ecosystems (Brundrett, 2009). Soil microbial communities, of which mycorrhizal fungi are an integral component, are central to soil fertility and can affect both crop productivity and cropping security (Rooney *et al*., 2009).Hayman (1982) reported that the populations of AMF vary greatly and their distribution is affected by various factors including soil, host plant, environmental conditions and agricultural practices.Variation of population and AMF diversity was affected greatly by variation of soil properties, environmental conditions, hosts specificity and destruction regime (Wubet *et al.,* 2004; Opik*et al.,* 2006; Verma *et al.,* 2008). In relation to aspect of habitat destruction, Johnson *et al.* (2013) explained that high intensity land use such as jhum lands could change soil properties and had implication on decrease of species richness and AMF diversity.

Mohammad *et al*. (2003) reported the lowest spore densities in his study due to decrease in organic matter and microbial activities. Other researchers found that AMF colonization and AMF spores density declined as a result of fallow (Black and Tinker, 1979; Kucey and Tinker, 1983; Singh *et al*., 2003). The decline in AMF population in the soil due to long fallow can be ameliorated by AMF inoculation was reported by Thompson (1987) and Thompson *(*1991). Sieverding (1990) also reported that population and diversity of AMF tends to increase under natural ecosystems compared to that under agro-ecosystems. This was attributed to the higher diversity of plant communities and to the management practices in agro-ecosystems that would exert negative effects on the AMF population

(RabatinandStinner, 1989). A total of 34 AMF species was reported by Singh *et al*. (2003) belonging to six genera namely, *Acaulospora* (6), *Enterophospora* (1), *Gigaspora (3), Glomus* (25), *Sclerocystis* (2) and *Scutellospora* (7) in jhum land of Arunachal Pradesh. Bordoloi *et al*. (2015) reported a total of 24 species of AM fungi belonging to 4 genera viz., *Glomus, Scutellospora, Acaulospora* and *Gigaspora* from the different land use system of Arunachal Pradesh of Eastern Himalayan region. They also reported that jhum land and tea garden had the least number of AM fungal species among their study sites due to high disturbance of fire and the application of fungicides.

CHAPTER 3

Materials and Methods

3.1 Study Sites Description

The study sites i.e., jhumlands were situated at Muallungthu village in Aizawl District, Mizoram, India. The topography is moderately steep with an average slope angle range of 20-26º.

Three different jhumlands were taken as study sites as follows:

(i) 3 years (Y1) 23°6'50"N, 92°7'26"E where there were different plantations like banana and other fruits. There was an intermittent crop plantation in this site.

(ii) 6 years (Y2). 23°59'59"N, 92°7'16"E. There was a pre plantation of banana in this site but the land was abandoned without any other plantation to recover the soil.

(iii) 10 years (Y3). 23°59'48"N, 92°7'18"E. This site also had a banana plantation and also the most disturbed site among the study sites. Weedicides were often used to kill weeds and the villagers used to collectlogs and fodder from this site.

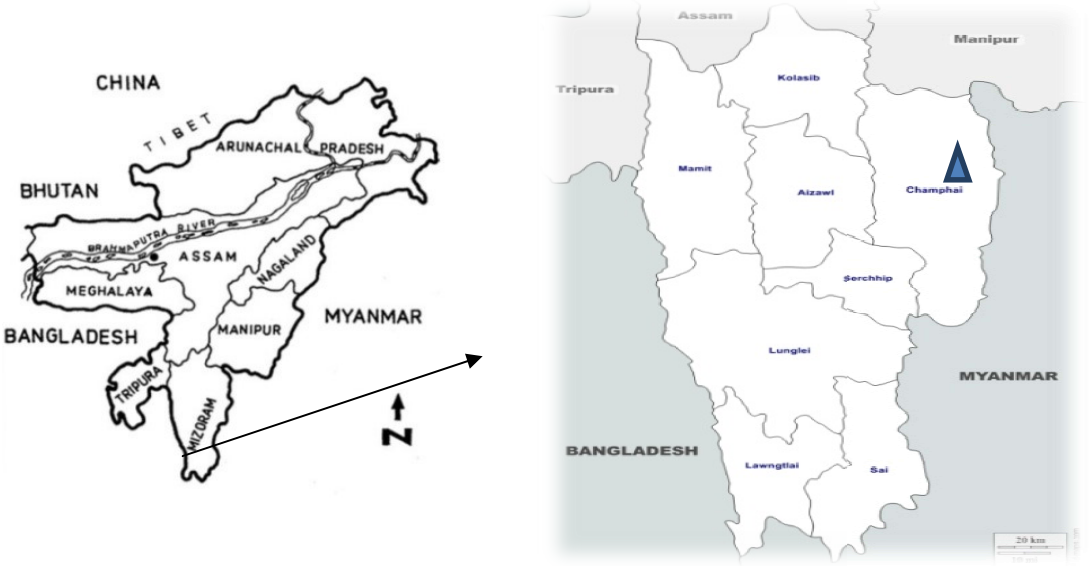


Fig. 1: Map of northeast India showing the study site in Mizoram. **Δ** represents the study area of different jhum land in Muallungthu.

Fig 2: A satellite image showing the different study sites of Jhum lands.

Fig 3: Y1 (3 years jhum fallows)

Fig 4: Y2 (6 years jhum fallows)

Fig 5: Y3 (10 years jhum fallows)

3.2. Sampling Methods

Three sampling plots of 100 m^2 were selected in each site. Soil sampling was done according to the growth period of the selected plants viz., cowpea, maize and banana.

a) For cowpea, soil sampling was done during the growing season of cowpea ie,. May – July 2016 and 2017. Cowpeas were sowed in the month of March in each of the sites. The fine roots and rhizosphere soil were collected for studied during this confined period.
b) Maize was sowed in the month of March in each of the sites. The fine roots and rhizosphere soil were taken for observing and quantifying mycorrhizal association and diversityduring their growth period i.e., May – August, 2016 and 2017.
c) Banana was pre planted plant in each study site. The fine roots and rhizosphere soil were collected for studied every month from October 2015 -August 2017. The samples were taken in a seasonal basis, differentiated into three season, Pre Monsoon (March to May), Monsoon (June to September) and Post Monsoon (October to February).
d) For studying effect on soil properties, soil sampling was done for two years, from January 2016- December 2017.

Soil samples were collected in sterile polythene bags using thin metal sheet soil sampler (10 cm diameter and 30 cm height) different depths of 0-10cm and 10-30 cm from 9 random locations with at least 5 m distance between two locations in each plot.

Soil samples close to rhizosphere region of the selected plants were collected from the jhum fallow sites for soil physico- chemical characteristics and mycorrhizal spores. The fine roots of the selected plants were also taken for morphological analysis of the mycorrhizal propagules. Mycorrhizal spores were also isolated from the rhizosphere region of the selected plants to study and identify species of AM fungi.

Fig 6: Images of cowpea from the study sites.

Fig 7: Images of maize from the study sites.

3.3AMF Assessment

3.3.1 Root colonization

For the analysis of mycorrhizal colonization in the plants, the root samples were washed free of soil and cut into 1cm long bits, cleared in 2.5% KOH at 90°C for 20-30 minutes, rinsed in water, acidified with 5N HCl and stained in lactophenol containing 0.05% Trypan blue (Phillips and Hayman, 1970). 50 segments approx. stained root samples were mounted on slides and examined for AM colonization under a compound microscope at 10x10 magnifications. Percent root colonization

was calculated (Dhar and Mridha, 2012). Percent root colonization was determined using the following formula:

$$\%\ RootColonization\ = \frac{No\ of\ Positive\ segments}{No\ of\ segments\ observed} x\ 100$$

3.3.2. Spore Counting and Identification

Mycorrhizal spores were extracted from three replicates of 50g soil by wet-sieving and decanting (Gerdeman and Nicolson, 1963). The decantant were fitered through a filter paper with grid lines. The filter paper were then spread on a glass plate and count under a dissecting microscope. Only the intact spores were counted under a dissecting microscope and expressed as spores per 50g of dry soil. The isolated spores were picked up with needle under a dissecting microscope and were mounted Melzer's reagent for identification. The complete and broken spores were examined using a compound microscope with a transmitted light illumination. All the spores were photographed with the help of camera (Moticam 2) attached to microscope. Taxonomic identification of spores to species level was based on sporocarpic size, colour, ornamentation and wall characteristics by matching original descriptions in INVAM and other available publications (Tulasne and Tulasne 1844; Nicolson and Gerdemann 1968;Trappe and Gerdemann 1974; Becker and Hall 1976; Gerd. And Bakshi 1976; Nicolson and Schenck 1979; Janos and Trappe 1982; Schenck and Smith 1982; Walker 1982; Berch and Fortin 1983; Rothwell and Victor 1984; Trappe *et al*., 1984; Smith and Schenck 1985; Koske *et al*., 1986; Miller and Walker 1986; Koske and Walker 1986; Sieverding 1987; Sieverding and Toro 1987; Almeida and Schenck 1990; Wu *et al*., 1995; Blaszk and Tadych 1997; Oehl *et al*., 2003; Oehl and Sieverding 2004; Walker and Schüßler 2010). Data on number of species, spore numbers and other physico-chemical characteristics were subjected to statistical analysis.

3.4 Diversity Indices

1. Shannon- Weaver diversity Index (Hs)(Shannon and Weaver, 1949)

$$Hs = -\Sigma piLnpi$$

where Pi = S / N,

S = number of individuals of one species

N = total number of all individuals in the sample site;

Ln = logarithm to base e

2. Simpson Index of Dominance (DS): (Simpson, 1949)

$$Ds = \sum \frac{ni(ni-1)}{N(N-1)}$$

Where, ni = No. of individuals of the species

N= total no. of individual

As the Simpson's index values increases, diversity decreases. Simpson index is therefore usually expressed as "1- D" or "1/D".

3. Margalef'sDiversity Index (DMg): (Margalef, 1958)

$$DMg = \frac{(S-1)}{LnN}$$

Where, S = number of species recorded

N = total number of individuals

Ln = Natural Logarithm

4. Pielou's Evenness Index (J'): (Pielou, 1966)

$$J' = \frac{H}{LnS}$$

Where, H = Shannon–Wiener's diversity index;

S = total number of species in the sample

Ln = Natural Logarithm

3.5 Soil Physico-Chemical Characteristics

3.5.1 Soil pH (Anderson and Ingram, 1993)

a. 10g of freshly collected soil was kept in a beaker containing 50ml of distilled water.

b. The soil water mixture was stirred for 20 minutes on a magnetic stirrer.

c. The solution was kept overnight and the pH was read by using electronic digital pH meter

3.5.2 Bulk Density (Anderson and Ingram, 1993)

Soil bulk density can be measured in terms of dry weight of unit volume of soil(g/cm^2 or g/ml). It includes both particle density and pore spaces and therefore is a function of pore spaces, particles shape, size and the degree of compactness. For determining bulk density,

Procedure:

(a) Dug out approximately 100 to 200g of soil from naturally packed land area.

(b) Filled up the gap created by digging with known volume sand. Volume of sand is determined by using a measuring cylinder.

(c) Keep the soil in a hot air oven at 110°C for 24hrs and take the weight of the soil after drying. The dry weight per unit volume of soil gives the bulk density.

$$\text{Bulk density} = \frac{\text{weight of oven dried soil (g)}}{\text{Vol. of soil core } (cm^3)}$$

Where,

Vol. of soil core = $3.14 \times r^2 \times h$

r = radius, h = height of soil corer

3.5.3 Soil Porosity (Anderson and Ingram, 1993)

Soil porosity refers to the percentage of space in a soil bulk that is occupied by interstitial degree of compactness determines the soil porosity. Soil porosity is an important physical property which determines soil moisture and air proportions. It can be measure by finding out the bulk density by using the formula given below:

$$\% \text{ Porosity} = 100 - \frac{(\text{Bulk density})}{2.65} \times 100$$

Where 2.65 is the standard particle density

3.5.5 Soil Temperature

The temperature of the soil is measured by digital soil thermometer. The sensor of the digital soil thermometer is driven inside the soil at the depth of 0 – 10 and 10 – 20cm. The reading is noted when it becomes constant. The requirements include digital soil thermometer, pen, paper, scale.

3.5.6 Soil Moisture Content (SMC) (Anderson and Ingram, 1993)

The moisture content of soil was determined by oven dry basis.

Procedure:

(a) 10g of freshly collected soil sample as kept in a hot air oven at 105°C for 24 hours.

(b) The percentage moisture content was calculated by the formula

$$\text{Moisture content}(\%) = \frac{W_1 - W_2}{W_2} \times 100$$

Where, W_1= initial weight

W_2= final weight

3.5.7 Soil Organic Carbon (Walkley and Black, 1934)

Organic Carbon is contained in the soil organic fraction, which consists of cells of micro-organisms, plants and animal residue at various stages of decomposition, stable humus synthesized from residues, and highly carbonized compounds such as charcoal, graphite and coal.

The organic matter (Humus) in the soil gets oxidized by chromic acids (potassium dichromate plus concentrated H_2SO_4) utilizing the heat of dilution of H_2SO_4. The unreacted dichromate is determined by back titration with ferrous ammonium sulphate.

$$2Cr_2O_7^{2-} + 3CO + 16H^+ = 4Cr^{3+} + 3CO^2 + 8H_2O$$

Dichromate method that used heat of dilution or minimal heating do not give complete oxidation of organic compound in the soil although the most active forms of organic carbon converted to carbon dioxide.

When iron (Fe^{2+}) is present in higher amount in soil, it will be oxidized to Fe^{3+} by $2Cr_2O_7^{2-}$, resulting in a positive error in the analysis, i.e., giving higher value for organic carbon content.

$$Cr_2O_7^{2-} + 6Fe^{2+} + 14\ H^+ = 2Cr^{3+} + 6Fe^{3+} + 7H_2O$$

Chemicals:

1. Potassium dichromate, $K_2Cr_2O_7$ (1N)
2. Diphenylamine indicator, $(C_6H_5)_2NH$
3. Orthophosphoric acid (85%)
4. Ferrous ammonium sulphate, $FeSO_4.(NH_4)_2SO_4.6H_2O$
5. Sulphuric acid, H_2SO_4 Conc.
6. Sodium fluoride, NaF.

Reagents:

1. Potassium Dichromate, 1N: Dissolve exactly 49.04g of AR (analytical grade) potassium dichromate (dried at 105˚C) in litre of distilled water.
2. Ferrous ammonium sulphate, 0.5N: Dissolve 196g of the hydrated crystalline ferrous ammonium sulphate per 1 litre containing 20ml conc. Sulphuric acid. This solution is relatively stable and convenient to work than that of ferrous sulphate.
3. Diphenylamine indicator: Dissolve 0.5g diphenylamine in a mixture of 20ml water and 100ml of conc.sulphuric acid.

4. Conc. Sulphuric acid (Sp gravity 1.84, not less than 96%) containing 1.25% silver sulphate: Add 15g of Ag_2SO_4 per litre of H_2SO_4 in case of soil free from chlorides use of silver sulphate can be avoided.

5. Ortho-phosphoric acid (85%) or sodium fluoride chemically pure.

Procedure:

Standardization of ferrous ammonium sulphate solution:

1. Take 10ml of 1N potassium dichromate solution in a 250ml conical flask.
2. Then very carefully add 20ml of Sulphuric acid. This will generate heat.
3. Swirl the mixture and allow cooling.
4. Add 200ml of distilled water.
5. Then add 10ml of Ortho-phosphoric acid and 1ml of diphenylamine indicator and mix thoroughly.
6. Add ammonium ferrous from the burette, swirl the flask, until the colour changes from blue to green.

Test of Organic Carbon:

1. The oven dried soil is grind and completely passed 0.2mm sieve (80 mesh) and 0.50g sample is placed at the bottom of dry 500ml conical flask.
2. Add exactly 10ml 1N Potassium dichromate in the conical flask and swirled the flask gently to disperse the soil in the dichromate solution. The flask is kept on asbestos sheet.
3. Add 20ml of concentrated sulphuric acid very carefully from a measuring cylinder. Swirl 2-3 times. The flask is allowed to stand for 30 minutes. Protect the flask from draught.
4. Add 200ml of the distilled water and 10ml of Ortho-phosphoric acid to get a sharper end point of the titration.
5. After the addition of 1ml diphenylamine indicator, the content is titrated with ferrous ammonium sulphate solution till the color flashes from blue to violet.
6. Simultaneously, a blank is run without soil.
7. If more than 7ml of dichromate solution is consumed, the determination is repeated with a small quantity (0.25 to 0.5g) of soil.

$$\text{Organic Carbon (\%)} = \frac{10\,(B-T)}{B} \times 0.003 \times \frac{100}{S}$$

Where,

B= Volume of Ferrous Ammonium Sulphate solution for blank titration in ml.

T= Volume of Ferrous Ammonium Sulphate solution needed for soil in ml

S= Weight of soil in gram.

3.5.7 Available Potassium (Standford and English, 1949).

The term available Potassium incorporates both exchangeable and water soluble forms of nutrients present in the soil. The readily exchangeable plus water soluble K is determined in the neutral normal ammonium acetate (1N NH_4OAc) extract of soil.

Preparation of standard curve:

1. 10 to 60ppm Potassium solution from the stock solution is prepared by adding ammonium acetate solution.

2. An appropriate filter is attached; the gas and air pressure is adjusted in the flame photometer.

3. The reading is adjusted to zero for the blank in the flame photometer.

4. The reading at different concentration for Potassium is noted down.

5. The reading from the flame photometer is plotted against the different concentrations of Potassium.

Procedure:

1. 5gm of soil is mixed with 25ml of neutral normal ammonium acetate solution and was shaked well.

2. The first few ml of the filtrate was rejected.

3. The Potassium concentration in the extract in the extract was determined by flame photometer by using Potassium filter.

Calculation:

$$\text{Available Potassium (mg of } Kg^{-1} \text{ of soil)} = \frac{A \times V}{W \times 100}$$

$$\text{Available Potassium (Kg/ha of soil)} = R \times \frac{V}{W} \times \frac{2.24 \times 10^6}{10^6}$$

Where,

A = K content of soil extract from standard curve, mg/L

V = Volume of the soil extract(ml)

W = Weight of air dry sample taken for extraction (g)

R = ppm of K in the extract (obtained from standard curve)

3.5.8 Available Phosphorus (Dickman and Bray, 1940)

Phosphorus is extracted from soil with 0.5M at nearly constant pH of 8.5 in calcareous, alkaline or neutral soil containing Calcium phosphate; this extractant decreases the concentration of Ca as $CaCO_3$. As a result the concentrations of Phosphorus in solution increase.

Preparation of Standard Curve:

Different concentration of Phosphorus (1,2,3,4,5 and 10ml of 2ppm of phosphorus solution) was taken in 25ml volumetric flask for the preparation of standard curve.

The standard concentration was prepared in the range of 0.08µg/ml to 0.80µg/ml as given in the table.

The curve was plotted taking the caloric meter reading on the vertical axis and the amount of phosphorus (in µg P/ml) in the horizontal axis.

Procedure:

1. 2.5g of soil and 50ml extracting solution solution ($NaHCO_3$) will be added in 250ml conical flask.
2. The flask will be shaked for 30mins with suitable shakers.
3. Filter the suspension through Whatman Filter paper No. 40.
4. The flask will be immediately shaked before the suspension is pour into the funnel.

Calculation:

The formula used for calculation of P is

$$\text{Olsen's Phosphorus (Kg/ha)} = \frac{R \times V/v \times 1/S \times (2.24 \times 10^6)}{10^6}$$

$$P = R \times (50 \times 5) \times (1/2.5) \times 2.24 = R \times 8.96$$

Where,

V = Total volume of extractant (50ml)

v = Volume of aliquot taken for analysis (5ml)

S = Wt. of soil (2.5g)

R = Wt.of P in the aliquot on µg (from standard curve)

3.5.9 Available Nitrogen (Anderson and Ingram, 1993)

The Kjeldahl method permits the available nitrogen to be precisely determined in the plant and in the soil. The method of determination involves three successive phases which are,

1. Digestion of the organic material to convert nitrogen into HNO_3.
2. Distillation of the released Ammonia into an absorbing surface or medium.
3. Volumetric analysis of the Ammonia formed during the digestion process.

Digestion:

Digestion of the organic material is carried out by digesting the sample with Con. H_2SO_4 in the presence of $CuSO_4.H_2O$ as a catalyst and K_2SO_4 which raise the digestion temperature. The organic material decomposes into several components i.e.,

$$C \rightarrow CO_2,\ O \rightarrow H_2O \text{ and } N \rightarrow NH_3$$

In the organic matter, some nitrates are present, most of which are lost during the digestion. The loss may be disregarded for most soils. Since the amount of NO_3^- - N is far lesser than the Organic Nitrogen.

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

Distillation:

The Ammonia content of the digest is determined by distillation with excess NaOH and absorption of the evolved NH_3 is in standard HCl.

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

$$NH_3 + HCl \rightarrow NH_4Cl$$

Volumetric Analysis:

The excess of standard HCl is titrated against standard NaOH using Methyl Red as an indicator. The decrease in the multi equivalence of acid as determined by acid-

base titration, which gives a measure of the N content of the sample. The end point is determined by a change of colour from pink to yellow.

$$2\ HCl + 2\ NaOH \rightarrow 2\ NaCl + H_2O$$

3.6Statistical Analysis

The individual soil parameters and AMF colonization were analysed for mean, mode, median, maximum, minimum, Skewness, Kurtosis, standard deviation and standard error using Microsoft excel. Pearson's correlation coefficient and one way ANOVA was analysed between mycorrhizal colonization, spore number and various soil parameters using SPSS version 20.0.

CHAPTER 4

Results and Discussions

4.1. Taxonomy of Arbuscular Mycorrhizal Fungi (AMF) Species.

Thirty one (31)AM fungal species were extracted from soil and taxonomically described. Twenty morphotypes belong to the genus *Glomus*, four genus of *Acaulospora*, one genus of *Enterospora*, three genus of *Funneliformis*, two genus of *Gigaspora and one genus of Rhizophagus*; *Glomus multicaule, G. aureum, G. geosporum, G. botryoides, G. ambisporum, G. macrocarpum, G. microcarpum, G. fasciculatum, Glomus fuegianum, G. microaggregatum, G. clavisporum, G. versiforme, G. clarum, G. diserticola, G. constrictum, G. glomeratum, G. taiwanese, G. maculosum, G. rubiforme, G. verruculosum, Acaulospora scrobiculata, A. tuberculata, A. laevis, A. foveata, Funneliformis mosseae, F. coronatum, F. badium, Gigaspora margarita, G. albida, Entrospora schenckii and Rhizophagus intradices.* Thirty one species from the rhizosphere of banana, fifteen species from the rhizosphere of cowpea and fifteen species from the rhizosphere of maize from the three jhum lands in Muallungthu. 31 different species belonging to 6 Genera were identified. *Acaulospora tuberculata, A. scrobiculata, Funneliformis mosseae, Glomus fasiculatum, G. botryoides, G. constrictum* and *Rhizophagus intradices* was found from all the study sites (Table 1).

Table 1: Identified species of AMF from different plants from different sites.

Banana	Maize	Cowpea
Acaulospora tuberculata	*Acaulospora laevis*	*Acaulospora tuberculata*
A. laevis	*A. tuberculata*	*A. scrobiculata*
A. scrobiculata	*A. scrobiculata*	*Funneliformis mosseae*
A. foveata	*Funneliformis mosseae*	*Funneliformis badium*
Entropospora schenckii	*Gigaspora margarita*	*Gigaspora margarita*
Funneliformis coronatum	*Glomus geosporum*	*Glomus constrictum*
F. badium	*G. fasciculatum*	*G. fasciculatum*
F.mosseae	*G. verruculosum*	*G. ambisporum*
Gigaspora albida	*G. microaggregatum*	

Glomus multicaule	*G. diserticola*	*G. microcarpum*
G. aureum	*G. clarum*	*G. versiforme*
G. geosporum	*G. fuegianum*	*G. glomeratum*
G. botryoides	*G. botryoides*	*G. aureum*
G. ambisporum	*G. maculosum*	*G. botryoides*
G. macrocarpum	*Rhizophagus intraradices*	*G. clavisporum*
G. microcarpum		*Rhizophagus intraradices*
G. fasciculatum		
G. fuegianum		
G. microaggregatum		
G. clavisporum		
G. versiforme		
G. clarum		
G. diserticola		
G. constrictum		
G. glomeratum		
G. taiwanese		
G. maculosum		
G. rubiforme		
Rhizophagus intradices		

1. ***Glomus aureum*** Oehl, Wiemken and Sieverding, J. Appl. Bot. 77: 111-115, 2003

Glomus aureum forms irregular sporocarps 45-160µm in diameter without a peridium composed of rather closely packed spores (Photo plate 1.1). Spores randomly embedded between interwoven hyphae which are red to orange red in Melzer's reagent. Spores subglobose to ovoid, seldom globose sometimes round. Spores have two wall layers, in total 1.5-4 µm thick. The innermost lamina of the laminated inner wall layer often closes the pore of the thick-walled hyphal attachment.

2. ***Glomus clavisporum*** (Trappe) Almeida and Schenck, Mycologia 82:710, 1990

Sporocarps orange to brown, globose to subglobose, tightly pack around a central plexus of interwoven hyphae without peridium (Photo plate 1.2). Spores orange to

brown 90-160µm, clavate to subcylinderic tapering to cylinderic subtending hyphae. Spore wall laminate, 2.5-6.0 µm thick on the side walls, thickened 16-22 µm at the apex and 5-9 µm at the base. No distinct reaction with Meltzer's reagent.

3. ***Glomus fuegianum*** (Spegazzini) Trappe and Gerdemann, Mycol. Mem. 5:58, 1974

Sporocarps present singly or contain 2-28 spores group radially arranged and tightly adherent spores developed from a thick-walled inflated hypha (Photo plate 1.3). Sporocarps light brown 430 x 540µm in diameter with a peridium. Peridium hyaline interwoven hyphae, usually present only on a part of a sporocarp. Spores yellowish brown, ovoid 80-150 µm with a single subtending hypha. Spores frequently surrounded by branched and convoluted hyphae. The wall composed of two layers.

4. ***Glomus glomeratum*** Sieverding, Mycotaxon 29:73-79, 1987

Sporocarps dark brown and irregular formed by interwoven, straight, curved and branched, pale orange hyphae, 350-550 µm in diameter (Photo plate 1.4). Sporocarps without a peridium. The interior of the sporocarps filled with an amorphous, colourless substance and with soil debris. Spores brown, globose to subglobose 50-65 µm in diameter. Two spore wall present. Outer layer is light orange to golden yellow, 5-10 µm thick. Inner layer is flexible, hyaline, usually tightly adherent to the inner surface.

5. ***Glomus macrocarpum*** Tulasne and Tulasne, Giorn. Bot. Ital. 2:55-63, 1844

Sporocarps in 4-15 distributed spores 350 µm in crushed state (Photo plate 1.5). Spores rarely single in the soil, yellow, globose to subglobose, 80-180µm in diameter mostly with one subtending hypha. Peridium not found. Wall composed of two distinct layers, outer layers is thin up to 2 µm; inner wall layer is yellow up to 6µm thick with a serious of laminations.

6. ***Glomus microaggregatum*** Koske, Gemma and Olexia, Mycotaxon 26:125-132, 1986

Sporocarp identified by its small size, hyaline colour of the spore, crushed sporocarp 600 µm. Spore diameter 40-70 µm (Photo plate 1.6).Wall thickness 1.32µm.

7. ***Glomus deserticola*** Trappe, Bloss and Menge, J., Mycotaxon 116: 106, 1984

Spores borne in the soil singly or in loose aggregates lacking a peridium, color ranges from pale yellow to orange, globose to subglobose, sometimes ovoid to pear-shaped 70-

200µm in diameter with one subtending hypha. The sporocarpic cell wall comprises two layers (Photo plate 1.7).

8. ***Glomus versiforme*** S.M. Berch, Canadian Journal of Botany 61 (10): 2614, 1983

Spores formed singly in the soil, pale yellow to deep yellow,globose to subglobose, 80-250µm in diameter usually with a single subtending hypha, sometimes with two to three subtending hyphae(Photo plate 1.8). Subcellular structure of spores has one wall with two layers. The two layers do not stain in Melzer's reagent.

9. ***Glomus clarum*** T.H. Nicolson and N.C. Schenck, Mycologia 71 (1): 182, 1979

Spores single in the soil, hyaline to pale yellow, globose to subglobose, sometimes ovoid, 70-290µm in diameter with one subtending hypha 15-80µm wide, becoming thinner with increasing distance from the spore (Photo plate 1.9). Subcellular structure of spores composed of one wall with three layers.

10. ***Glomus multicaule*** J.W. Gerdemann and B. K. Bakshi. 1976. Endogonaceae of India: Two new species. *Trans. Br. Mycol. Soc.* 66:340-343.

Spores formed only singly in soil; ellipsoid, broadly ellipsoidal, subglobose, or occasionally triangular; 149-250 µm in diameter (Photo plate 1.10). Spore wall described as having a single layer 8.6-34 µm thick (thickest at base of spore), with rounded projections 1.2-3.7 µm long regularly distributed over the spore surface. Subtending hyphae, number of which varies from 1-4, with much of the material comprising type specimens having at least two hyphae rarely positioned adjacent to each other. The multiple attached hyphae and very thick ornamented spore wall distinguish this species from other glomeromycotan fungi described to date.

11. ***Glomus geosporum***(Nicolson and Gerd.), C. Walker, Mycotaxon 15: 56, 1982

Spores formed singly in the soil, light to dark brown in colour, globose to subglobose sometimes ovoid. Spores 110-290µm with a single subtending hypha. Subcellular structure of spores of one wall with three layers (Photo plate 1.11). Spore walls 4-8µm thick.

12. ***Glomus ambisporum*** G.S. Sm. and *N.C. Schenck, Mycologia 77 (4): 566, 1985*

Spores occur only in sporocarps formed intercalary by swelling of nonseptate or septate hyaline to pale orange hyphae (Photo plate 1.12). Sporocarps light orange to golden yellow; globose, subglobose, rectangular, flattened or irregular, 250-675µm formed by

interwoven, nonseptate or septate, straight, curved and branched, hyaline to pale orange hyphae, 2-6 µm diam, with a wall 0.1-0.5µm thick. Sporocarps without a peridium, with a knobby surface shaped by the surface of tightly packed spores. Spores light orange to golden yellow, globose to sunglobose, 40-70µm diam. Subcellular structure of spores consists of a spore wall comprise two layers.

13. ***Glomus microcarpum*** Tul. and C. Tul., Giornale Botanico Italiano 1 (2): 63, 1844

Spores rarely single in the soil, usually in sporocarps with some to almost 100 spores randomly distributed (Photo plate 2.13). Spores pale yellow to golden yellow, globose to subglobose, rarely ovoid, 20-55µm with one subtending hypha. Sporocarps 180–730µm without a peridium. Subcellular structure of spores composed of one wall with two layers.

14. ***Glomus fasciculatum*** (Thaxt.) Trappe and Gerd., Mycologia Memoirs 5: 51, 1974

Spores single in the soil or in aggregates with 2-20 spores lacking a peridium, light brown to reddish brown in colour, globose to subglobose, 50-150µm diameter with one subtending hypha (Photo plate 2.14). Subtending hyphae often pale in colour than the spore. Subcellular structure of spores composed of one wall with three layers.

15. ***Glomus constrictum*** Trappe, Mycotaxon 6 (2): 361, 1977, *Funneliformis constrictum* (Trappe) C. Walker and A. Schüßler, The Glomeromycota: 14, 2010

Spores single in the soil, brownish orange to dark brown to black colour, globose to subglobose, 100-330 µm, with one suntending hypha (Photo plate 2.15). Spore walls 7-15µm thick, straight with a short funnel shaped projection. Just beyond the the point of attachment the hypha constricted to 10-22µm diam. Subcellular structure of spores consists of one wall containing two layers. The two layers do not stain in Melzer's reagent. Most juvenile spores have one spore layer only.

16. ***Glomus verruculosum*** Blaszk, Mycologia 89 (5): 809, 1997.

Spores formed singly in the soil, yellow to orange, globose to sub globose sometimes ovoid, 145-220µm in diameter with a single subtending hypha (Photo plate 2.16). It has three layers which do not stain in Melzer's reagent.

17. ***Glomus botryoides*** F.M. Rothwell and Victor, Mycotaxon 20 (1): 163, 1984.

Spores single to cluster, globose to subglose, 140-250µm in diameter (Photo plate 2.17). Reddish brown to black at maturity, spore wall consists of two walls. Attached hyphae straight to recurved, point of attachment frequently inflated, 38-45µm in diameter.

18. ***Glomus taiwanense*** (Wu and Chen) Almeida and Schenck, Mycologia 82:711-712, 1990.

Sporesglobose , brown to dark brown, 190-250µm in diameter(Photo plate 2.18). Chlamydospores formed radially in a single, tightly packed layer around a central plexus of hyphae. Chlamydospore outer wall is reddish brown and inner is light brown.

19. ***Glomus rubiforme*** (Gerdemann and Trappe) Almeida and Schenck, Mycologia 82:709-710, 1990

Spores occur in sporocarp in the soil. Sporocarps yellow brown; subglobose; 190-250 µm diam without a peridium; with 22-24 spores (Photo plate 2.19). Spores light brown; globose to subglobose; 44-57 µm diam; with a single subtending hypha; developed from a thick-walled, inflated hypha, wall thickness 5-10 µm; spores arranged radially to form a blackberry-like sporocarp when mature.

20. Glomus maculosum Miller, D. D. and C. Walker. 1986. *Glomus maculosum* sp. nov. (Endogonaceae): an endomycorrhizal fungus. *Mycotaxon* 26:217-227.

Spores are formed singly in the soil on one to three subtending hyphae; hyaline when immature, becoming pale straw-colored to ochraceous when mature, globose to subglobose, 95-220 µm in diameter (Photo plate 2.20). Spore wall structure of three layers (L1, L2 and L3). The outer layer (L1) is thin, hyaline, 0.3-1.0 µm thick, tightly adherent to L2, sloughing with age. The middle layer consists of finely adherent sublayers (or laminae), pale straw-colored to ochraceous, 4-13 µm thick. Subtending hypha straight to sharply recurved, parallel-sided, or funnelshaped, sometimes constricted at the spore base.

21. ***Funneliformis mosseae*** (T.H. Nicolson and Gerd.) C. Walker and A. Schüßler, The Glomeromycota: 13, 2010, Nicolson & Gerd., Mycologia 60 (2): 314, 1968

Usually formed clusters; yellow-brown to brown; peridium surrounding these spores is 10-38 µm thick, with robust hyphae mixed with many finer branching hyphae. The peridium does not alter spore wall structure, and appears to be a labile character (usually being lost after several successive cultures) (Photo plate 2.21). Spore color straw to dark orange-brown but a majority are yellow-brown, globose to subglobose, some irregular, 100-260 µm. Subcellular structure of spores consists of one wall containing three layers.

22. ***Funneliformis coronatum*** (Giovann.) C. Walker and A. Schüßler, The Glomeromycota: 13, 2010

Color ranges from pale orange brown to dark orange brown, with most orange brown, globose to subglobose, some irregular, 80-220µm. Subcellular structure of spores contain two wall layers(Photo plate 2.22). The outer one often absent in mature spores.

23. ***Funneliformis badium*** (Oehl, D. Redecker and Sieverd) C. Walker and A. Schüβler, The Glomeromycota: 13, 2010.

Spores were brownish orange to reddish brown mainly ovoid to irregular, sometimes globose to subglobose 250-680µm in diameter with 4-43 spores, radially originated from hyphal plexus and separated by an interspore mycelium and occasionally by cystidium like structures. Spore wall comprising three layers (Photo plate 2.23). Sporocarps lack peridium.

24. ***Acaulospora scrobiculata*** Trappe, Mycotaxon 6 (2): 363, 1977

Spores borne singly in the soil, produced literally on the neck of a soporiferous saccule, yellowish white to pale yellow, globose to subglobose, 90-135 µm diam. Spore consists of a spore wall and two inner germination walls. Spore wall composed of three layers (Photo plate 2.24). The three layers do not react in Melzer's reagent.

25. ***Acaulospora tuberculata*** Janos and Trappe, Mycotaxon 15: 519, 1982

Spore color ranges from red orange to dark red brown, globose to subglobose, 120-280µm diam. Consist spore wall and two inner germination walls. Spore wall composed three layers (Photo plate 3.25). Three layers (L1, L2 and L3), the outer layer continuous with the wall of the neck of the parent sporiferous saccule and the latter two are synthesized with development of the spore.

26. ***Acaulospora laevis*** TrappeandGerd., Mycologia Memoirs 5: 33, 1974

Spore color ranges from salmon to orange brown, most pale orange brown, globose to subglobose, 140-240µm (Photo plate 3.26). Spores consist of a three-layered spore wall and two bi-layered flexible germinal walls. Layers of the spore wall differentiate sequential (L1 to L3), after which each of the germinal walls differentiate sequentially (gw1 to gw2). Three layers (L1, L2, and L3), the outer one continuous with the wall of the neck of the parent sporiferous saccule and inner two synthesized as the spore expands from the saccule neck. L2 and L3 are formed sequentially during spore wall differentiation.

27. ***Acaulospora foveata*** Janos and Trappe. 1982. *Mycotaxon* 15: 515-522.

Spore globose to subglobose, sometimes irregular. 240-360 µm in size (Photo plate 3.27).Red-orange to dark red-brown. Immature spores initially are cream-colored and gradually acquire an orange tint as the spore wall begins to differentiate Three layers (L1, L2 and L3) are usually evident, with the outer layer continous with the wall of the neck of the parent sporiferous saccule.

28. ***Gigaspora margarita*** W.N. Becker and I.R. Hall, Mycotaxon 4 (1): 155, 1976

Spores produced singly in the soil, blastically at the tip of a bulbous sporogenous cell (Photo plate 3.28). Spores yellowish white to sunflower yellow, globose to subglobose, sometimes ovoid, 200-480 µm. Subcellular structure of spores consists of a spore wall and a germination wall. Spore wall composed of two layers.

29. ***Gigaspora albida*** Schenck and Smith 1982, Mycologia 74(1): 85

Spore globose to subglobose. 200 – 280 µm in size, Cream with pale green tint. Three layers (L1, L2, and L3), the first two adherent and of equal thickness in juvenile spores, with L2 thickening as the spore wall is differentiated. L3 differentiates as a prelude to germ tube formation (Photo plate 3.29).

30. ***Entrophospora schenckii*** Sieverding and Toro 1987, *Mycotaxon* 28:209-214.

Spore completely hyaline (sparkling white) when mature. Mostly globose, subglobose, but also ellipsoid to ovoid.50-80 µm in diameter (Photo plate 3.30).Spore wall consisting of three hyaline layers (L1, L2 and L3), all of which exhibit some flexibility in broken section. As a result, the spore wall contains numerous folds from any or all of the layers.

31. ***Rhizophagus intraradices***(N.C. Schenck and G.S. Sm.) C. Walker and A. Schüßler, The Glomeromycota: a species list with new families and new genera: 19 (2010).

Spores are white, pale cream to yellow brown, sometimes with a green tint. Color is highly variable within this continuum. Globose, subglobose, irregular, with many spores elliptical. 40-140 μm in diameter (Photo plate 3.31). Three layers (L1, L2 and L3), with only the first layer present in juvenile spores and subtending hyphal wall (so they are colorless); L2 and L3 then formed sequentially in both the spore wall and in the wall of the subtending hypha.

Among the isolated genera of AMF, *Glomus* was the most dominant AMF genus from all the study sites. This could be due to the higher capacity of tolerance to stress and unfavorable conditions (Ruiz-Lozano *et al*., 1995). Sharma *et al*. (1984 and 1986) also reported that *Glomus* species was the dominant species among the AMF in Northeast India. *Glomus glomerulatum* always have two subtending hyphae which is in accordance with other report (Sieverding, 1987). *Acaulospora laevis* spores consist of a three-layered spore wall and two bi-layered flexible germinal walls as described by Trappe and Gerdemann (1974). *G. fuegianum* was isolated in this study which is also reported to be an extremely rarely occurring in the world (Das and Kayang, 2009). *Gigaspora margarita* was also isolated, the size and structure was found to be in accordance with Becker and Hall (1976). *Funneliformis mosseae* was also isolated from maize in this study which was reported to have importance in toxic resistance and growth of root length in maize (Flores *et al*., 2017). *Glomus fasciculatum* was also found to be present in all the study sites which was also reported by Azmat *et al*. (2016) as an important bio-converter and bio-activator of solubilization of Phosphorus into the ionic form. *Glomus aureum* as observed forms irregular sporocarps without a peridium embedded between interwoven hyphae which was also in confirmity as suggested by Oehl *et al*., (2003). *Acaulospora tuberculata* as observed showed spore wall and two inner germination wall which could be seen clearly as described byJanos and Trappe (1982). *Glomus clavisporum* observed has pack around a central plexus of interwoven hyphae with subcylinderic tapering structure as reported by others (Almeida and Schenck, 1990). A single dark brown spore of *G. constrictum* with one subtending hypha is in accordance with

Trappe (1977). *G. Verruculosum* is observed as formed singly in the soil with one subtending hypha (Blaszk, 1997). *G. macrocarpum*is always found in clusters with two layers without peridium (Tulasne and Tulasne, 1844) while that of *G. microcarpum* can be differentiated from its small size (not more than 55µm) as compared to *G. macrocarpum*. An ovoid to pear shaped of *G. Deserticola* spores borne in the soil singly or in loose aggregates lacking a peridium, pale yellow to orange with size of 70 -115µm diameter is in accordance withTrappe *et al.,* (1984). *G. microaggregatum* can be identified by its small size, hyaline colour of the spore and spore diameter 40-140 µm (Koske *et al.,* 1986). Pale orange brown to dark orange brown and having two wall layers with the size of 80 - 220µm describe the characteristic features of *F. coronatum* (Walker and Schüßler, 2010). Sporocarps like *F. badium, F. mosseae, G. multicaule, G. microcarpum, G. botryoides, G. ambisporum, G. aureum, G. clavisporum, G. fuegianum, G. macrocarpum* and *G. microaggregatum* also formed clusters and usually lack peridium. They can be distinguished according to their size, structure and cell wall layers. *A. scrobiculata* has the characteristic features of three wall layers and two germinal layers and has a sporiferous succule at the neck as described by Trappe (1977). *G. geosporum* has the characteristic features of one wall with three layers and one subtending hypha as described by Nicholson and Gerdemann (1972). A blackberry like structure confirmed *G. rubiforme* with the report of Almeida and Schenck (1990). *G. taiwanese* can be differentiated from *G. clavisporum* through their distinctly different spore size and separate hyaline layers (Wu, 1993). *Entrophosphora schenckii* and *Rhizophagus intradices* also gives the assemblage of AMF species with a description of their sporocarpic structures used for the identification from the selected three plants.

4.2 Arbuscular Mycorrhizal Association in *Vigna sp.*(Cowpea)

The result on the study of the AMF colonization of the roots showed significant evidence of the extent of fungal colonization on cowpea plants with respect to different jhum fallow period (Photoplate 4).

The highest colonization was found to be 60% (SD±7.023) and 59% (SD±2.17) in Y2 in both 2016 and 2017 and the least colonization was 45% (SD±2.645) and 46.33% (SD±3.05) in Y3 in the year 2016 and 2017 respectively.

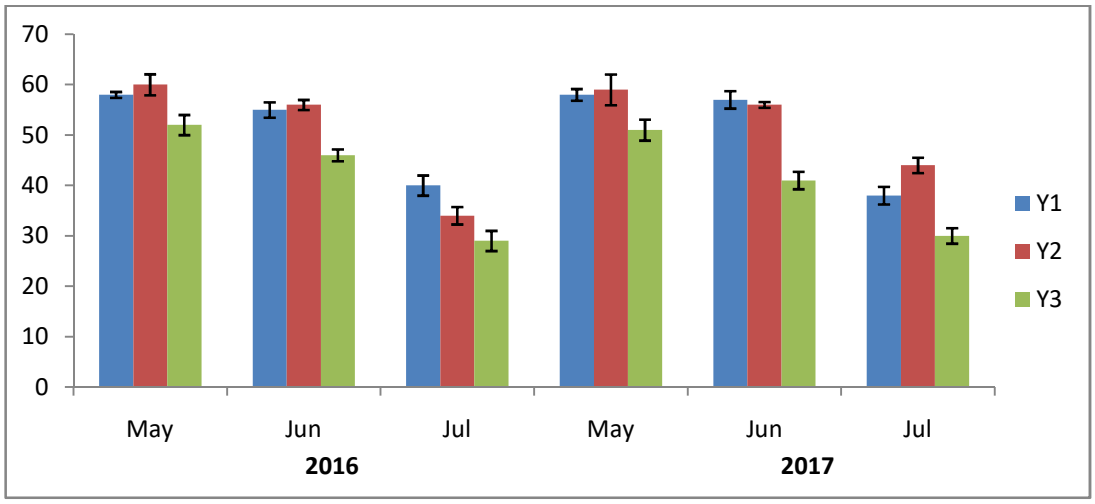


Figure 8: Percentage of colonization of AMF in roots of cowpea in 2016 and 2017.

Figure 8 showed that the percentage of AMF colonization in cowpea decreases from May to July in both years. The average percentage of colonization in figure 8 showed that Y1 had the highest percentage colonization in the year 2016 while the highest percentage colonization was Y2 in 2017. There was an increase in percentage colonization in Y2 while slight decrease was found in Y3 from 2016 to 2017 while the percentage of colonization remains the same in both years in Y1. Y3 has a longest jhum cycle of 10years, and was expected to be restored of its fertility.

It was found that it had the lowest colonization of AMF. This may be due to continuation of human exploitation which alters the productivity of the soil. Reduction in the rate of host root infection, formation and colonization of AM fungi have been reported from disturbed soils (Bellgard, 1993; Mc Gonigle *et al*., 1990; Antunes *et al*., 2006).

A one way ANOVA (Table 2) was conducted to compare the effect of different ages of jhum on AMF colonization in Cowpea (Appendix I).

Table 2. AMF colonization in Cowpea.

Site	2016	2017
Y1[a]	51±5.56[c]	51±6.50[c]
Y2[b]	50±8.08[c]	53±4.58[c]
Y3[c]	42.33±5.84[ab]	40±6.11[ab]

N=54, Mean ±SE followed by different letters of treatments are significantly different at 0.05 level according to Tukey's HSD. There was a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 3.357$, $p=0.000<0.05$.

Post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2, $p= 0.855>0.05$, while a statistical difference was in Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.009< 0.05$ in the year 2016. There was also no statistical difference between Y1 & Y2, $p= .986>0.05$ however, there was a statistical difference between Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.001< 0.05$ in the year 2017. A significant difference between AMF colonization within the three different jhum lands may be due to their age differences, human exploitation and regeneration of soil.

4.3. Arbuscular Mycorrhizal Association in *Zea mays*L.(Maize)

The AMF colonization in maize from the three different jhum fallow sites showed significant variation during their growth period from the month of May to August during 2016 and 2017. (Photo plate 5)

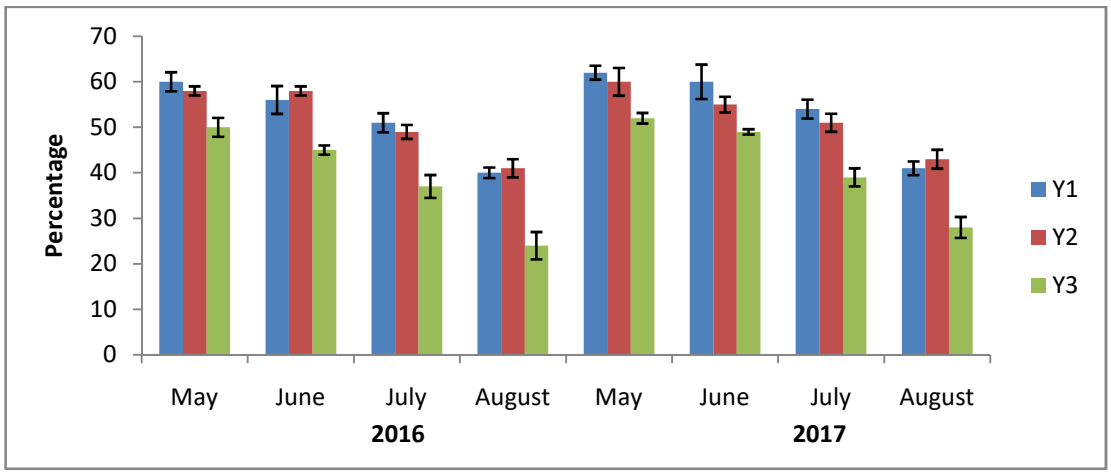


Figure 9: Percentage colonization of AMF in roots of maize in 2016 and 2017.

The highest AMF colonization was found to be 51.75% (SD±8.65) and 54.25% (SD±9.46) in Y1 in both 2016 and 2017 and the least colonization was 39% (SD±11.34) and 42`% (SD±10.86) in Y3 in the year 2016 and 2017 respectively.

The percentage of AMF colonization in maize decreases from May to July in both years (Figure 9). Y1 has the highest colonization percentage in both the years. There was an increase in colonization percentage in Y3 while slide decrease was found in Y1 and Y2 from 2016 to 2017. Y1 had the most AM colonization among the three study sites. This may be due to the tendency of AMF to stabilizing soil structure, increasing tolerance to water stress, soil salinity and drought, soil compaction, root pathogens and heavy metals or others toxic substances present in the soil (Augé, 2001; Feng *et al*., 2002; Trotta *et al*., 2006; Hildebrandt *et al*., 2007; Siddiqui and Pichtel, 2008; Raviv, 2010; Miransari, 2011b). Y3 has a longest jhum cycle of 10years, and was expected to produce higher colonization than the other study sites. However it was found that it had the lowest colonization of AMF. This may be due to continuation of human exploitation which alters the productivity of the soil. Reduction in the rate of host root infection, formation and colonization of VAM fungi have been reported from disturbed soils (Mc Gonigle *et al*., 1990; Bellgard, 1993; Goss and de Verennes, 2002).

A one way ANOVA was conducted to compare the effect of different ages of jhum on AMF colonization in maize (Appendix II).

Table 3. AMF colonization in Maize.

Site	2016	2017
Y1[a]	51.75±4.32[c]	54.25±4.73[c]
Y2[b]	51.5±4.09[c]	52.25±3.59[c]
Y3[c]	39±5.67[ab]	42±5.43[ab]

N=72, Mean ±SE followed by different letters of treatments are significantly different at 0.05 level according to Tukey's HSD. There was a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment ($F (5, 71) = 5.856$, $p = 0.000<0.05$).

Post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2 ($p= 0.982>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.017< 0.05$) and Y1 & Y3 ($p=0.001< 0.05$) in the year 2016. There was no statistical difference between Y1 & Y2 ($p= 0.732>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.000< 0.05$) and Y1 & Y3 ($p=0.007< 0.05$) in 2017. The results in this study do not provide evidence for a beneficial effect of increased duration of fallow on mycorrhizal colonization in maize between Y1 and Y2, but clearly demonstrate the effect of anthropogenic pressure on the land. The significant AMF colonization between Y1 and Y3 & Y2 and Y3 shown by one way ANOVA could be due to the difference between the levels of human exploitation. Within Y2 the land was left alone to replenish itself while Y3 was grazed to collect logs and fodders by the villagers. Since AM fungi are an obligatory symboints, high anthropogenic pressure on vegetation reduces the development of AMF (Duponnois *et al*., 2001).

4.4.Seasonal Variationin Associationof Arbuscular Mycorrhizal Fungi in *Musa sp.* (Banana)

The study on AMF colonization on a seasonal basis showed a significant variation among the roots of banana with respect to different jhum fallow periods as shown in figure 10. (Photo plate 6)

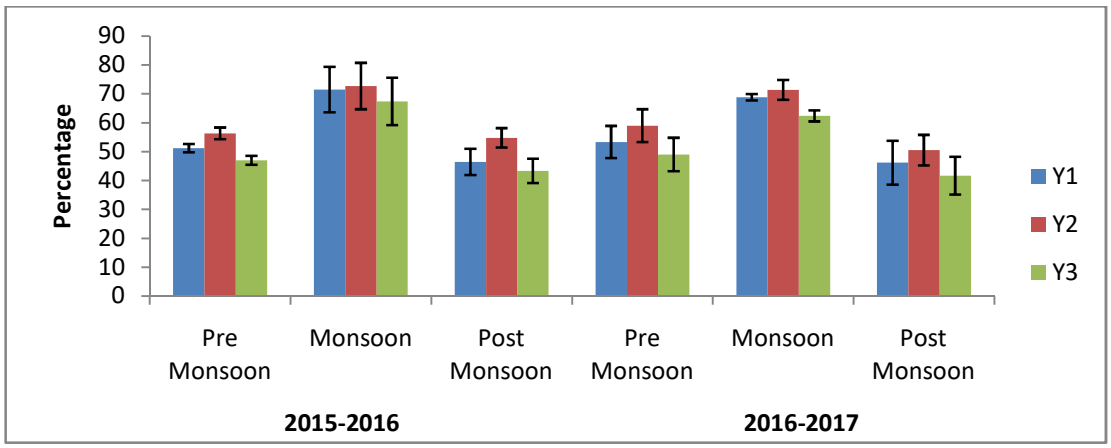


Figure 10: Percentage of colonization of AMF in roots of banana seasonally, 2015-2016 and 2016-2017.

The different jhums fallows showed different results of root colonization percentage. There was a decline in colonization from Y2 to Y1 then Y3 (Fig.10). Y2 has the highest colonization percentage in every season while Y3 has the lowest. The highest AMF colonization percentage was found during monsoon season followed by pre-monsoon. Post-monsoon season had the least percentage of AMF colonization.

It was also observed that the colonization of AMF was lower during pre- and post- monsoon period and higher during monsoon season. This may be due to higher rainfall and warm climate which may be favourable for the colonization of AMF. During the rainy season, fine root production stimulates AMF spore germination and mycorrhization resulting in higher total AM colonization and low spore abundance (Cuenca and Lovera, 2010).Percent root colonization and mycorrhizal spore counts steadily increased in rainy season was reported by several workers (Raghupathy and Mahadevan, 1993; Kumar *et al*., 2013).AM fungal species richness is influenced largely by the intensity of disturbances (Helgason *et al*., 1998; Kozoil and Bever, 2017) which inturn affect AMF colonization. Other edaphic factor may also affect

the colonization of AMF. Further, cold temperatures can also limit AMF sporulation and the allocation of host C to AMF (Ruotsalainen *et al*., 2009). Oehl *et al*. (2010) also reported that soil type strongly affect AMF composition and the occurrence of many species. Effect of reduction of AMF propagules due to compaction of soil from 30% to 50% when a forest soil is severely disturbed or exposed have also been recorded by Ahmad (1996).Y2 had the highest colonization percentage among the three study sites. Higher AMF colonization and abundance in un-disturbed lands than that of disturbed lands was observed by Borstler *et al*. (2008) suggesting that soil disturbances due to natural and anthropogenic activities often affect negatively on AMF population.

A one way ANOVA was conducted to compare the effect of different ages of jhum on AMF colonization in Banana during pre- monsoon, monsoon and post monsoon season (Appendix III).

Table 4: Seasonal colonization of Arbuscular Mycorrhizal fungi in banana.

	Pre-monsoon		Monsoon		Post-monsoon	
	2015-2016	2016-2017	2015-2016	2016-2017	2015-2016	2016-2017
Y1[a]	51±1.527[bc]	53.33±9.626[c]	71.25±2.322[c]	68.75±1.108[c]	46±4.472[c]	46±7.536[c]
Y2[b]	55.67±2.33[ac]	59±8.020[c]	72.5±2.061[c]	71.25±3.40[c]	54.6±3.370[b]	50.2±5.122[c]
Y3[c]	46.67±3.511[ab]	49±8.185[ab]	67±1.732[ab]	62.25±1.931[ab]	43.2±4.176[a]	41.6±6.462[ab]

In pre-monsoon season, N=54, Mean ±SE followed by different letters of Treatments are significantly different at 0.05 level according to Tukey's HSD. There was a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 7.217$, $p=0.000<0.05$.

For monsoon season, N=72, Mean ±SE followed by different letters of Treatments are significantly different at 0.05 level according to Tukey's HSD. There was a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment i.e. $F (5, 71) = 16.214$, $p=0.000<0.05$.

While for post monsoon season, N=90, Mean ±SE followed by different letters of Treatments are significantly different at 0.05 level according to Tukey's HSD. There was a significant effect of jhum on AMF colonization at p< 0.05 level for the three treatment i.e. F (5, 71) = 2.557, p=0.003<0.05.

Post hoc comparisons using the Tukey's HSD for pre monsoon season indicated that there was statistical difference between Y1 & Y2 (p= 0.031>0.05), Y1 & Y3(p=0.047< 0.05) and Y2 & Y3(p=0.030<0.05) in the year 2015-16. There was no statisticalvariation between Y1 & Y2 (p= 1.000>0.05) while there was a statistical difference between Y1 & Y3 (p=0.001< 0.05) and Y2 & Y3 (p=0.003< 0.05) in the year 2016-17. During the monsoon season the Tukey's HSD indicated no statistical difference between Y1 and Y2 (p= 0.998>0.05) while there was a statistical difference between Y1 & Y3 (p= 0.001<0.05), and Y2&Y3 (p=.000< 0.05) in the year 2015-16. It also showed no statistical difference between Y1 and Y2 (p= 1.000>0.05) while there was a statistical difference between Y1 and Y3 (p=0.000< 0.05) and Y2 & Y3 (p=0.000< 0.05) in the year 2016-17.The Tukey's HSD for post monsoon season indicated no statistical difference between Y1 & Y2, (p= 0.855>0.05) and Y2 & Y3 (p=0.059< 0.05)while there was a statistical difference between Y1&Y3 (p=.000< 0.05) in the year 2015-16. It also showed no statistical difference between Y1 and Y2 (p= 0.986>0.05) while there was a statistical difference between Y2&Y3 (p=.010< 0.05) and Y1 and Y3 (p=.001< 0.05) in the year 2016-17. A rough picture can be hence made on the effect of the seasonal variation and environmental conditions from the results drawn from the pre-monsoon, monsoon and post monsoon study.

Some authors suggested that AMF colonization and spore numbers are positively influenced by the rainfall. According to them (He *et al.*, 2002; Oliveira and Oliveira, 2005), seasonal precipitation induces root growth, leading to enhanced germination of AMF spores and subsequent colonization. In other investigation (Guitton,1996), only AMF spores were influenced by the seasonal precipitation. AM colonization varies with change of season. Seasonal effects also influence the establishment of plants under field conditions, depending on the efficiency of indigenous fungi (Hindumathi and Reddy, 2011).

4.5. Diversity of Arbuscular Mycorrhizal Fungi in Cowpea (*Vigna sp.*)

The total number of species identified from the rhizosphere was 15 belonging to 5 genera (Table 5). 12 species were found to occur in Y1and Y3 while 13 numbers of species was found in Y2. The Simpson dominance index showed a high dominance in Y3 as compared to Y1 and Y2 (Table 5). Pielou's evenness index E showed a lowest in Y1 in 2016 which determines the lowest uniform distribution and highest in Y2 in the year 2017 indicating that the distribution of AMF is uniform in this study sites. Shannon Weaver index of diversity was found to be lowest in Y3 (2017) and highest in Y2 (2017). Increase in diversity was found from 2016 and 2017 in all the study sites.

Table 5: Diversity index of Arbuscular Mycorrhizal association with Cowpea from three different jhum lands.

Diversity index	Y1		Y2		Y3	
	2016	2017	2016	2017	2016	2017
Taxa S	11	12	12	13	12	13
Dominance D	0.11	0.12	0.18	0.13	0.17	0.19
Simpson 1-D	0.88	0.87	0.81	0.86	0.82	0.80
Shannon H	1.88	1.93	1.93	2.16	2.01	1.87
Eveness E	0.71	0.77	0.75	0.81	0.80	0.72
Margalef's	10.81	11.81	11.81	12.82	11.81	12.81

The low index of dominance 0.11and 0.12 in Y1in the year 2016 and 2017 indicates shared dominance of several AMF species is higher than that of Y2 and Y3 which has the higher value of 0.18, 0.13, 0.17 and 0.19 in the year 2016 and 2017 respectively. Species richness and evenness was found to be highest in Y2 in the year

2017 while lowest diversity as well as evenness was found to be in Y1 in 2016. The dominant species were found from 3 species viz., *Glomus fasciculatum, Rhizophagus intradices and Funneliformis mosseae* which contribute more than 65% of the total species observed. In each study sites the dominant species contribute more than 60% of the total population. The population was highest in Y2 where there were no human disturbances or interferences. This result is in accordance with Singh *et al*. (2003). The most frequent species found was *Glomus* contributing 60% of the number of species recovered from the different study sites. This result is in agreement with Das and Kayang (2009). Sharma *et al*. (1984 and 1986) also reported that *Glomus* species were suspected to be the most common Genus of AMF species in northeast India.

Table 6: Abundance of AMF spores in from the three different sites in Cowpea. (Appendix No- 7 a-c)

Name of	Y1		Y2		Y3		Total
Species	2016	2017	2016	2017	2016	2017	
Acaulospora tuberculata	3	5	2	2	3	5	20
Acaulospora scrobiculata	2	5	0	0	4	2	13
Funneliformis mosseae	74	72	69	57	32	60	364
Funneliformis badium	0	0	24	34	16	21	95
Gigaspora margarita	3	1	0	0	4	3	11
Glomus constrictum	0	14	4	3	6	5	32
Glomus fasciculatum	47	50	41	46	56	52	292
Glomus ambisporum	8	9	8	4	9	0	38
Glomus microcarpum	7	11	4	3	0	0	25
Glomus versiforme	0	0	3	4	0	0	7
Glomus glomeratum	9	7	3	3	3	4	29
Glomus aureum	0	0	22	16	0	0	38
Glomus botryoides	11	12	9	9	5	11	57
Glomus clavisporum	14	6	0	34	24	12	90
Rhizophagus intradices	61	64	63	36	63	45	332
Total	239	256	252	263	255	220	1485

The number of spores was found to be highest in Y2(515) and lowest in Y3 (475) as shown in Table 6. The lowest AMF spore density may be due to frequent human exploitation. There had been often human activities like ploughing, fire, logging etc., in these sites. Several anthropogenic influences are also known to decrease mycorrrhizal diversity, or at least cause changes in species composition. These include forest harvest (Jones *et al*., 2003), wildfire (Dahlberg, 2002), atmospheric N deposition (Lilleskov *et al*., 2002), acid rain (Roth and Fahey, 1998), fertilization (Treseder, 2004) and tillage (Jansa *et al*., 2003). The effects of anthropogenic disturbances on EM fungi have also been discussed by Erland and Taylor (2002).

The occurrence of AMF species as shown in Table 6 showed the appearance of species which do not have a definite pattern. This may be due to their difference in life cycle and their limit of tolerance to different disturbances. Different factors can influence the AMF life cycle, such as temperature, luminosity, dynamics of plant species,rainfall, soil fertility, root exudations, and competition with other microorganisms and possible interactions with them (Moreira *et al.,* 2007). The composition of AMF community may be strongly affected by the individual plant species through differential effects on hyphal growth and sporulation (Bever *et al.,* 1996). Seely (1991) and Jacobson (1997) reported that biotic factors are relatively less important than abiotic factors for establishing population patterns and found that the duration of moisture availability determines the level of AMF colonization. Level of soil fertility is believedto be an important factor influencing the AMF population (Hayman, 1982). Several researchers reported a reduction in AMF population under high levels of soil P (AlMomany,1989; Xu *et al*., 2014). Bordoloi *et al*. (2015) reported that the distribution of AM fungal species was affected by plant species composition, particularly the ground vegetation coverage and level of disturbance. The relationship between spore density, species richness, and the distribution frequency of AMF with different soil characteristics is a result of the interactions between all of these factors andcould be specific for each case (Sivakumar, 2013).

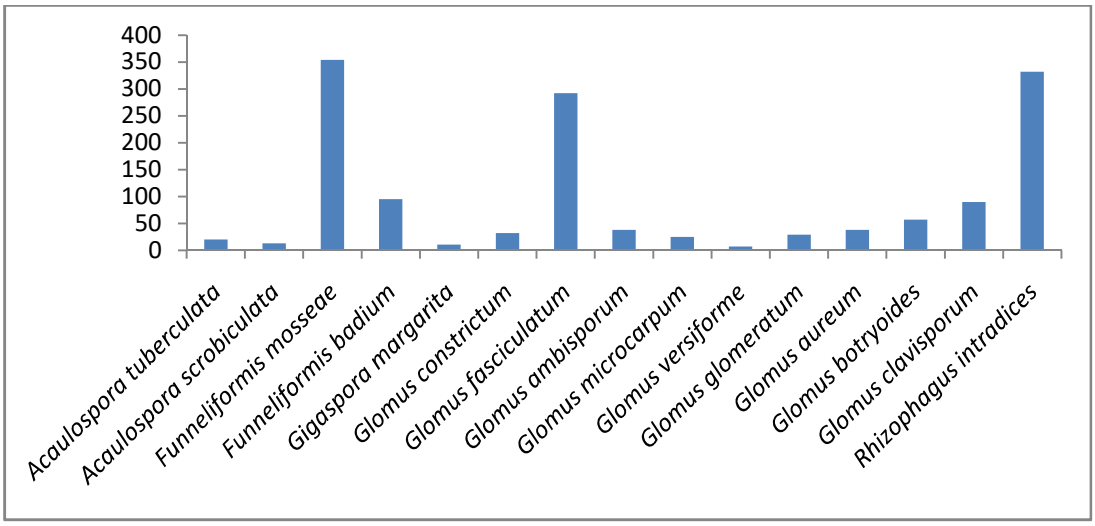


Figure 11. Total number of AMF spores counted from the three study sites.

Funneliformis mosseae (formerly *Glomus mosseae*) was the most abundant AMF species recovered from cowpea contributing 24.5% of the whole AMF population followed by *Rhizophagus intradices (*formerly *Glomus intradices)* with 22.3% and *Glomus fasciculatum* contributing 19.6% of the population. The high percentage of dominance of these species could be due to their ability to tolerate stress and play a potential role in the development of their host plants. Salinity is one of the major agricultural problems especially at jhum fallows. Intermittent farming and irregular crop rotation could cause high acidic soil which was observed in Y1. Wu *et al*. (2010) reported that inoculation of *Funneliformis mosseae* in plants could induce tolerance to high acidic soil. It also improves water absorption capacity by plants by increasing root hydraulic conductivity and maintaining osmolarity (Auge 2001). *Glomus fasciculatum* in cowpea not only improves growth and development but also improve resistant to soil borne pathogen (Sundaresan *et al.* 1993).

The soil physico-chemical properties given in figure 11 was analysed with species richness and population of spores using Pearson's correlation (Table 7). Soil moisture content showed a positive correlation with number of species (0.181) while negative correlation (-0.338) with number of spores in Y1. A negative significant correlation (-0.922**) was found between species diversity and soil moisture content while an insigificant positive correlation (0.015) was found in Y2. However, a

positive correlation was found between soil moisture content (0.251) and number of species (0.641) and number of spores was found in Y3. Soil temperature showed positive correlation with both number of species and number of spores in all the study sites except in Y3 where number of spores showed negative correlation (-0.478). Bulk density was also found to have a positive correlation with both species richness as well as number of spores in all the study sites while porosity showed negative correlation only with species richess in Y2. A negative correlation between pH with number of species and number of spores was found in Y1 while positive correlation was observed in Y3. Organic C showed a positive correlation with both species richness and spore population in all the sites except in Y2 where it had a negative correlation (-0.411) with species richness and in Y3 a negative correlation was found with population of spores (-0.058). A significant negative correlation was also found between available N and number of spores (-0.863*) in Y3 while no significant negative correlation was found with P. There was negative correlation with both species richness and spore population in all the sites except in Y3 where species richness showed a positive correlation (0.083)with P. Available K was found to have a significant negative correlation (-0.816*) with species richness in Y2.

Table 7: Pearson correlation between different soil parameters, number of species and abundance of spores in roots of Cowpea.

Variables	Y1		Y2		Y3	
	Species	Spores	Species	Spores	Species	Spores
SMC	0.181	-0.338	-0.922**	0.015	0.251	0.641
Temp	0.442	0.242	0.587	0.444	0.022	-0.478
Bd	0.462	0.273	0.172	0.441	0.357	0.327
Porosity	0.462	0.273	-0.174	0.429	0.357	0.327
pH	-0.023	-0.769	-0.706	0.199	0.641	0.185
C	0.708	0.283	-0.411	0.012	0.330	-0.058
N	0.180	-0.233	-0.702	0.094	-0.715	-0.863*

P	-0.650	-0.159	-0.110	-0.336	0.083	-0.131
K	0.023	0.246	-0.816*	-0.294	-0.003	0.350

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

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

Where SMC=Soil moisture content, Temp=Soil temperature, BD= Bulk density C= soil organic carbon, N= Available Nitrogen, P= Available Phosphorus and K= Available Potassium.

It has been reported that AMF species composition and spore density were found to have highly variability and influence by plant characteristics and a number of environmental factors such as soil pH and soil moisture content (Boddington and Dodd, 1999). One way ANOVA analysis between the different ages of jhum lands and species richness showed a significant variation $r=.016$; $p<0.05$. This showed that species richness was also affected by the ages of jhum fallows. However, one way ANOVA (Appendix IV) analysis showed no significant variation between different ages of jhum lands and number of spores ($r=.374$; $p>.05$). Akond *et al*. (2008) found a result which is in contrast to the present study. In this study, the species richness and spore density were affected by P which was in contrast with Matthimaran *et al*. (2007). The density of spores influence by P was also reported by Zerihu *et al*. (2013). Similar findings were also reported from India and Northern Europe (Udaiyan *et al*., 1996; Kahiluoto *et al*., 2001). However, there was also a report that P and N applied together in soil results in greater number of spores while only N enrichment increase spore abundance and decrease hyphal length density (Sheng *et al*., 2013). The reason for having high number of spores in Y2 might be attributed with some other edaphic factors since it has been reported that AMF behavior is affected by soil pH,nutrient level and interactions with other micro-organisms (Burrows and Pfleger. 2002)

4.6. Diversity of Arbuscular Mycorrhizal Fungi in Maize (*Zea maize L*).

A total of 15 species were recovered from maize belonging 5 genera. Y2 has got the highest diversity as analysed by Shannon diversity index containing 14 and 15 different species in the year 2016 and 2017 respectively while Y1 had 12 and 11 species in the years 2016 and 2017 respectively having lowest diversity and Y3 had 13 species in 2016 and 12 species in 2017. Pielou's evenness showed highest value of 0.83 in Y1 in 2016 while the lowest value was 0.76 found in the year 2016 in Y3.The higher value of evenness indicates more equal distributions of species as compared to the other sites. The result in this study showed highest species richness in an undisturbed area (Y2) than the other jhum lands Y1 and Y3 where there is a regular disturbance. Margalef's species richness was highest in Y2 (14.81) in the year 2017. This result is in agreement with Singh *et al*.(2003) who reported that the AMF population and diversity was higher in undisturbed site of natural forest than the disturbed site of jhum land. Simpson dominance index was found to be highest in Y2 (0.87) in the year 2016 and lowest in Y1 (0.81) in the year 2017. A one way ANOVA (Appendix V) show no significant variation between different ages of jhum lands with species richness ($r=.354$; $p<0.05$) and abundance of spores ($r=.868$; $p<0.5$). Mathimaran *et al*. (2007) reported that the species richness of AMF spore communities in the field soils were not affected by crop rotation, P fertilization or by their interaction but plant species identity. The effect of different environmental conditions and different composition of plant cover affecting relative species abundance and diversity of AMF communities in maize was reported by Bever *et al*. (1996) and Jansa *et al*.(2002). Turnau *et al*. (2001) also reported the effect of high pH and salinity on species richness. The fact that the abundance of spores was not affected by different ages of jhum lands is possibly due to different geographic, soil and climatic context as well as due to different AMF functional properties in the different sites.Several authors reported that high soil P and N content caused a reduction in infection and number of AM spores (Kiers *et al*., 2011; Yang *et al*., 2013; Li *et al*., 2013) as well as decreasing the dependency of the plant on the fungalassociation (Zhang *et al*., 2017).

Table 8: Diversity index of Arbuscular Mycorrhizal association with Maize from three different jhum lands.

Diversity index	Y1		Y2		Y3	
	2016	2017	2016	2017	2016	2017
Taxa S	12	11	14	15	13	12
Dominance D	0.16	0.18	0.12	0.15	0.17	0.17
Simpson 1-D	0.83	0.81	0.87	0.84	0.82	0.82
Shannon H	1.95	2.04	2.25	2.06	1.92	1.97
Eveness E	0.85	0.81	0.83	0.78	0.77	0.79
Margalef's	10.82	10.82	13.82	14.82	12.82	11.81

The most frequent species was found to be *Glomus* species contributing 60% of the total species identified from maize followed by *Acaulospora* which was in consistent with Choudhury *et al*.(2006). Three (3) different species of *Acaulospora* was identified. This may be due to the high competitive nature of *Glomus* and *Acaulospora* as all individual species of AMF compete for resources through a combination of strategies resulting in the maintenance of diverse AMF community (Koske, 1987). The composition of AMF community as strongly affected by individual species through differential effects on hyphal growth and sporulation was reported by Bever *et al*.(1996).

Table 9:Abundance of AMF spores in from the three different sites in Maize (Appendix 8 a-c)

	Y1		Y2		Y3		
Name of Species	2016	2017	2016	2017	2016	2017	Total
Acaulospora laevis	4	7	5	2	4	4	26
Acaulospora tuberculata	6	0	3	3	0	3	20
Acaulospora scrobiculata	0	5	3	4	4	3	14
Funneliformis mosseae	80	73	40	71	62	71	397
Gigaspora margarita	0	0	2	1	0	0	3
Glomus geosporum	3	6	8	3	3	4	27

Glomus fasciculatum	41	25	40	57	50	40	253
Glomus verruculosum	0	0	4	0	2	2	8
Glomus microaggregatum	27	13	27	34	0	0	101
Glomus diserticola	13	0	19	13	11	24	80
Glomus clarum	7	9	11	7	7	8	49
Glomus fuegianum	20	26	54	35	59	34	228
Glomus botryoides	12	19	8	20	11	10	80
Glomus constrictum	5	6	7	7	6	0	31
Rhizophagus intradices	62	82	56	70	70	52	382
Total	260	291	287	327	289	255	1709

Table 9 showed that Y2 had the most abundance spore while Y3 had the least AMF spore abundance among the three different studied jhum lands. Abiotic stress such as low and high temperature, drought, salinity in the soil affecting AMF communities and abundance was reported by (Augé, 2001; Ben Khaled *et al.,* 2003; Miransari *et al*., 2008; Zhu *et al.,* 2010) which may decrease the number of spores in Y1 and Y3.

There are two dominant species in Y1 *Rhizophagus intradices* and *Funneliformis mosseae* which account for 53.9% of the total spores counted. *Glomus fasciculatum, G. fuegianum, G, microaggregatum, Rhizophagus intradices and Funneliformis mosseae* were the dominant species in Y2 contributing more than 85% of total AMF spores while *G. fasciculatum, G. fuegianum, R. intradices and F. mosseae* were the dominant species in Y3 which contribute more than 60% of the total spores counted.

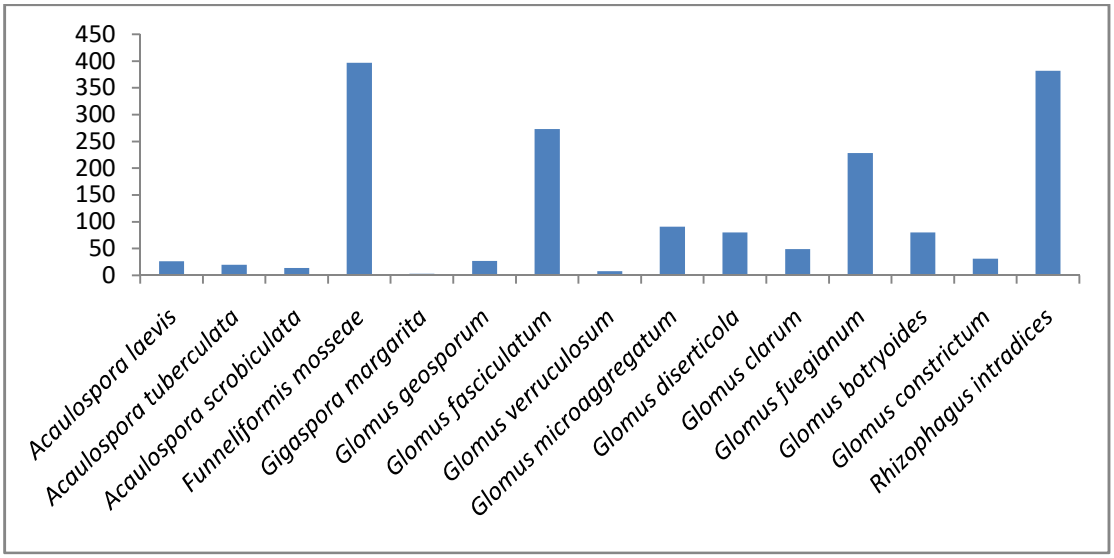


Figure 12: Total number of AMF spores counted from the three study sites.

Among the 15 species recovered from the rhizosphere of maize, *Glomus fasciculatum, G. fuegianum, Rhizophagus intradices* and *Funneliformis mosseae* were the most abundant species from the whole spores counted which accounted for 14.8%, 13.3%, 22.3% and 23.2% respectively. These four species contribute more than 70% of the whole population. The reason for higher abundance of these species could be attributed to the favourable soil environmental conditions of the jhum fallow sites to establish a permanent symbiosis with their host plants. AM species occurring in these sites would have the ability to complete their life cycle in the presence of their host plants.

The occurrence of AMF species from Table 9 showed an irregular pattern. This may be due to different life cycle of AMF species or may be due to pro-long human interventions that decline the AMF population when the jhum lands were prepared for cultivation. The reduction of soil fertility due to agriculture lowering the AM fungi propagules as compared to the soil which is kept in its natural state was reported by Roldan *et al.*(1997). The structure and diversity of AMF affected by biological and abiotic factors have been reported by (Lauber *et al.*, 2008; Berg and Smalla, 2010; Guyonnet *et al.*, 2018; Hugoni *et al.*, 2018). The decrease in AM fungal species diversity could also be attributed to uncontrolled burning of dried slash in the field for cultivation. Despite of all the factors mentioned *Glomus*

fasciculatum, G. fuegianum, Rhizophagus intradices and *Funneliformis mosseae* were found to thrive well in maize. Urbanova *et al*. (2015), reported that plant species is the dominant factor influencing soil fungi community composition.

Pearson's correlation done between the important soil physico-chemical properties and number of species and abundance of spores was given in table 10. A negative correlation was found between soil moisture and abundance of spores (-0.218) in Y1 and species richness in Y2 (-0.579) and Y3 (-0.013). Temperature showed a positive correlation with species richness in Y1 (0.205) and Y2 (0.257) and abundance of spores in Y2 (0.099) while a negative correlation was found both with species richness and abundance of spores in Y3. Bulk density showed a negative correlation only in Y2 with both species richness (-0.314) and number of spores (-0.006) among the three study sites while porosity had a negative correlation with number of species in Y1 (-0.007) and number of spores in Y3 (-0.234).

Table 10: Pearson correlation between different soil parameters, number of species and abundance of spores in roots of Maize.

Variables	Y1		Y2		Y3	
	species	spores	species	spores	Species	spores
SMC	0.117	-0.218	-0.579	0.653	-0.013	0.538
Temp	0.205	-0.153	0.257	0.099	-0.321	-0.435
Bd	0.069	0.023	-0.314	-0.006	0.200	0.110
Porosity	-0.007	0.129	0.333	0.187	0.047	-0.234
pH	-0.153	-0.269	0.137	0.431	-0.265	0.206
C	-0.159	0.009	-0.080	-0.019	-0.096	0.156
N	0.373	0.047	0.159	-0.453	-0.153	-0.626*
P	-0.619	-0.796*	0.321	-0.228	-0.306	-0.281
K	-0.282	-0.517	0.118	-0.338	-0.112	-0.089

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

pH was found to have a negative correlation on number of species (-0.159) and number of spores (-0.269) in Y1 and number of species in Y3 (-0.265) while a

positive correlation in Y2 and spore population in Y3. No significant correlation was found on organic C, however a negative correlation was found with number of species in Y1 (-0.159), Y2 (-0.080) and Y3 (-0.096) while number of spores had negative correlation only in Y2 (-0.019). A significant negative correlation was found between N and number of spores in Y3 (-626*) and between species richness and P in Y1 (-0.796*). Mohammad *et al*. (2003) also reported a negative correlation of spore abundance with P which is contrast with the reports of Singh *et al*. (2003). In contrast to this result, increase in P level in soil causing a decrease in spore abundance was reported by Kahiluoto *et al*. (2001) and Allison and Goldberg, (2002). High level of N and P in the field supressed the AMF diversity and spore production was reported by Liu *et al.* (2012). K was found to have a positive correlation (0.118) only with number of species in Y2.

4.7. Seasonal Diversity of Arbuscular Mycorrhizal Fungi in Banana (*Musa sp.*)

A total of 29 species was identified from the rhizosphere of banana. The highest species richness was found during monsoon season followed by pre-monsoon and the least was found during post monsoon season. Among the three study sites, Y2 has got the highest species i.e., 26 out of 29 species in the year 2016-17 while Y3 had the least with 15 species in the year 2015-2016. Pielou's evenness was found to be highest (0.90) during post-monsoon season in Y3 in the year 2015-16 while lowest (0.68) was during monsoon season in Y1 in the year 2015-16. Simpson dominance index showed highest during monsoon season in Y1(0.92) in both 2015-16 and 2016-17 while lowest during post monsoon season in the year 2016-17 in Y3 (0.86). Shannon diversity index and Margalef's diversity index showed highest during monsoon season in Y2 in the year 2016-17 with 2.59 and 25.83 respectively. This may be due to higher rainfall and warm climate which may be favourable for the colonization of AMF. During the rainy season, fine root production stimulates AMF spore germination and mycorrhization resulting in higher total AM colonization and low spore abundance (Cuenca and Lovera, 2010). Other edaphic factor may also affect the colonization of AMF. Further, cold temperatures can also limit AMF sporulation and the allocation of host C to AMF (Ruotsalainen *et al*.,

2009). This result is in contrast with D'Souza and Rodrigues (2012) who reported the least amount of species richness and spore abundance during monsoon season in mangroves. However, Suresh and Nelson (2015) found a maximum diversity during monsoon season while a minimum diversity was found during pre-monsoon season. There have been many reports on the nature of redistribution and diversity of mycorrhizal fungi in the disturbed soil environments (Mc Gonigle *et al.,*1990; Bellgard, 1993; Ahmad, 1996; Duponnois *et al*., 2001). Singh *et al*. (2003) reported a significant decrease in propagule populations, species abundance and diversity of VAM fungi in the jhum fallow site even after five years of regeneration period as fallow land after slash-and-burn agriculture in comparison to natural forest site.A one way ANOVA (Appendix VI) done between species richness and different years of jhum land shows significant variation ($r=.000$; $p<0.05$) and also between different seasons with species richness show significant variation ($r=0.013$; $p<0.05$). There is significant evidence pointing to the importance of soil conditions in controlling of mycorrhizal fungal communities (Bruns, 1995; Erland and Taylor, 2002). Any disturbances in the soil may cause decrease in population and diversity of AMF. When a soil is put to agricultural use it undergoes a series of physical, chemical and microbiological changes (Bellgard, 1994; Roldan *et al.,*1997) which may result in certain loss of micro-organisms. This may be the reason why Y1 and Y3 had the lesser species than Y2.The higher species richess during monsoon season reveals the importance of soil moisture for symbiotic function of AMF with plants while species richness found during the dry season showed the importance of AMF to stress water condition. Sharma *et al*. (2014) also reported higher diversity in an undisturbed forest than disturbed forest in Karbi Anglong Hills of Assam, India.

Table 11: Seasonal diversity index of Arbuscular Mycorrhizal Fungi from three different jhum lands in the year 2015-2016.

Species indices	Y1			Y2			Y3		
	Pre Monsoon	Monsoon	Post monsoon	Pre monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
Taxa S	23	24	18	23	23	20	19	20	15
Dominance D	0.095	0.072	0.11	0.099	0.097	0.11	0.103	0.08	0.101

Shimpson 1-D	0.904	0.92	0.88	0.9	0.902	0.88	0.89	0.91	0.89
Shanon H	2.43	2.17	2.44	2.53	2.52	2.41	2.101	2.46	2.45
Eveness	0.713	0.82	0.90	0.80	0.80	0.80	0.77	0.68	0.84
Margalef's	22.82	23.82	17.82	22.83	22.83	19.82	18.82	19.83	14.82

Table 12: Seasonal diversity index of Arbuscular Mycorrhizal Fungi from three different jhum lands in the year 2016-2017.

Species indices	Y1			Y2			Y3		
	Pre Monsoon	Monsoon	Post monsoon	Pre monsoon	Monsoon	Post Monsoon	Pre Monsoon	Monsoon	Post Monsoon
Taxa S	20	22	19	24	26	21	18	21	16
Dominance D	0.093	0.076	0.102	0.093	0.105	0.094	0.09	0.11	0.13
Shimpson 1-D	0.906	0.92	0.89	0.906	0.89	0.905	0.9	0.88	0.86
Shanon H	2.58	2.31	2.43	2.37	2.59	2.54	2.25	2.42	2.2
Eveness	0.77	0.79	0.79	0.74	0.79	0.83	0.86	0.74	0.82
Margalef's	19.82	21.83	18.82	23.82	25.83	20.83	17.82	20.82	15.82

Table 13,14 & 15 showed that the highest spore population was found in Y2 and also during monsoon season from all the study sites while lowest population was found during post monsoon season. These results illustrated that soil parameters like soil moisture content and temperature had a significant influence on the abundance of spores. The low temperature during post monsoon season may have an adverse effect on sporulation of AMF. Moreover, winter season is known for its dormant period for many plants and microbes until the temperature raises since February onwards (Bhardwaj and Chandra, 2018). However, the abundance of spores do not show any significant variation with different ages of jhum lands ($r=.143$; $p>0.05$) while different seasons showed a significant variation ($r=.000$; $p< 0.05$). Mane *et al*. (2017) reported a significant variation in spore density due to seasonal influence. Moreira-Souza *et al*. (2003) also demonstrated that sporulation is influenced by a strong seasonal effect. Higher spore density during pre-monsoon may be attributed to soil temperature as high soil temperature favours AM fungal sporulation (Hayman, 1970; Saravanakumar *et al*., 2008). Speciesrichness and AMF diversity were probably related with host species, lifecycle and specific site condition as reported by other workers (Opik *et al.,*2006). Harinikumar and Bagyaraj (1988) and Mallesha

and Bagyaraj (1991) reported that AM fungi sporulate during winter in the tropics. The optimum temperature for sporulation by mycorrhizal fungi appears to be around 25°C.

Table 13: Abundance of AMF spores in Banana from Y1 during Pre-Monsoon, Monsoon and Post Monsoon season (Appendix 9 a-c).

	Pre-Monsoon		Monsoon		Post Monsoon		
Name of species	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	Total
Acaulospora tuberculata	5	3	3	5	4	1	21
A. laevis	0	0	0	0	0	0	0
A. scrobiculata	1	4	4	2	2	1	14
A. foveata	3	3	1	6	0	0	13
Entrophospora schenckii	4	4	3	5	0	0	16
Funneliformis coronatum	3	3	2	1	4	2	15
F. badium	11	50	0	9	12	0	82
F.mosseae	60	51	48	64	49	42	314
Gigaspora albida	0	0	6	4	2	6	18
Glomus multicaule	35	15	12	30	48	17	157
G. aureum	25	26	42	33	21	34	181
G. geosporum	2	0	2	0	1	5	10
G. botryoides	12	17	9	8	0	0	46
G. ambisporum	0	11	0	0	0	0	11
G. macrocarpum	3	0	2	3	5	10	23
G. microcarpum	5	8	7	2	4	16	42
G. fasiculatum	35	39	24	28	16	19	161
G. fuegianum	21	21	25	38	24	50	179
G. microaggregatum	0	0	17	65	44	24	150
G. clavisporum	20	0	0	0	3	0	23
G. versiforme	7	4	0	0	1	2	14
G. clarum	5	3	6	4	4	2	24
G. diserticola	17	19	9	0	13	14	72

G. constrictum	4	0	5	6	4	8	27
G. glomeratum	0	5	3	7	2	0	17
G. taiwanese	0	0	0	0	0	0	0
G. maculosum	2	6	5	0	0	0	13
G. rubiforme	5	8	6	6	0	14	39
Rhizophagus intradices	47	33	34	64	5	33	216
Total	332	333	282	394	268	290	1888

Table 14: Abundance of AMF spores in Banana from Y2 during Pre-Monsoon, Monsoon and Post Monsoon season.

Name of species	Pre-Monsoon		Monsoon		Post Monsoon		Total
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	
Acaulospora tuberculata	24	31	9	7	0	0	71
A. laevis	1	2	2	2	3	2	12
A. scrobiculata	1	1	1	6	2	4	15
A. foveata	2	2	2	2	1	2	11
Entropospora schenckii	6	0	4	23	2	1	36
Funneliformis coronatum	1	3	2	1	1	2	10
F. badium	14	22	44	0	13	32	125
F.mosseae	40	62	48	44	67	42	303
Gigaspora albida	2	2	4	0	0	0	8
Glomus multicaule	36	36	36	26	56	30	220
G. aureum	23	21	0	17	0	0	61
G. geosporum	0	9	2	3	15	3	32
G. botryoides	7	8	13	7	5	8	48
G. ambisporum	0	3	5	1	0	0	9
G. macrocarpum	9	2	0	3	0	5	19
G. microcarpum	5	2	0	6	30	14	57
G. fasiculatum	24	15	0	46	2	28	115
G. fuegianum	14	32	69	21	26	31	193
G. microaggregatum	57	21	38	48	30	12	206
G. clavisporum	0	0	32	44	0	0	76

G. versiforme	13	3	4	5	0	0	25
G. clarum	0	3	4	1	6	1	15
G. diserticola	0	0	0	0	0	0	0
G. constrictum	1	1	0	5	4	9	20
G. glomeratum	2	7	1	4	8	0	22
G. taiwanese	0	0	33	25	25	50	133
G. maculosum	1	2	1	3	0	6	13
G. rubiforme	23	0	4	14	11	18	70
Rhizophagus intradices	75	64	33	116	38	41	367
Total	381	354	391	480	345	341	2292

Table 15: Abundance of AMF spores in Banana from Y3 during Pre-Monsoon, Monsoon and Post Monsoon season.

Name of species	Pre-Monsoon		Monsoon		Post Monsoon		Total
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	
Acaulospora tuberculata	1	3	0	1	0	5	10
A. laevis	0	0	3	1	5	4	13
A. scrobiculata	1	3	3	2	0	0	9
A. foveata	3	1	2	1	0	0	7
Entrospora schenckii	0	0	23	0	0	0	23
Funneliformis coronatum	0	0	0	0	0	0	0
F. badium	6	18	30	5	24	22	105
F.mosseae	40	63	27	79	44	43	296
Gigaspora albida	0	0	0	0	0	0	0
Glomus multicaule	29	20	24	0	12	0	85
G. aureum	11	27	67	28	20	5	158
G. geosporum	0	0	0	0	11	0	11
G. botryoides	4	10	11	9	9	7	50
G. ambisporum	0	0	5	1	0	4	10
G. macrocarpum	12	0	5	2	0	0	19

G. microcarpum	0	4	0	7	12	12	35
G. fasiculatum	27	41	71	36	28	31	234
G. fuegianum	0	31	27	26	27	21	132
G. microaggregatum	18	24	14	25	24	24	129
G. clavisporum	30	0	0	0	0	0	30
G. versiforme	5	0	0	1	0	6	12
G. clarum	4	6	5	12	8	4	39
G. diserticola	11	22	0	0	0	0	33
G. constrictum	0	0	4	4	8	4	20
G. glomeratum	2	7	0	0	10	4	23
G. taiwanese	18	16	0	2	0	0	36
G. maculosum	3	0	6	7	0	0	16
G. rubiforme	7	18	0	20	0	0	45
Rhizophagus intradices	78	56	24	66	68	69	361
Total	310	370	356	335	310	265	1941

A total of 29 species belong to six genera were identified from banana viz., *Glomus, Acaulospora, funneliformis, Rhizophagus, Gigaspora and Entrophospora. Glomus* and *Acaulospora* species were the most frequent species. The most abundant species in Y1 was found to be *Funneliformis mosseae* which accounts for 16.63% while *Rhizophagus intradices* was found to be the most frequent species in Y2 and Y3 contributing 16.01% and 18.6% respectively. Out of 29 species, 19 species belong to *Glomus* and 4 species belong to *Acaulospora*, 3 species of *Funneliformis* and 1 species each from *Rhizophagus*, *Gigaspora* and *Entrophosphora* were identified. Stutz *et al*. (2000) reported *Glomus* species to be the most widely distributed species that are found in different geographic regions and are adaptable to adjustment of sporulation patterns in varied environmental conditions (Strutz and Morton, 1996). *Glomus* species are found to dominate cold, temperate and tropics regions (Mukerji *et al*., 2002). *Acaulospora* species are found frequently associated with acidic soil (Abbott and Robson, 1991).

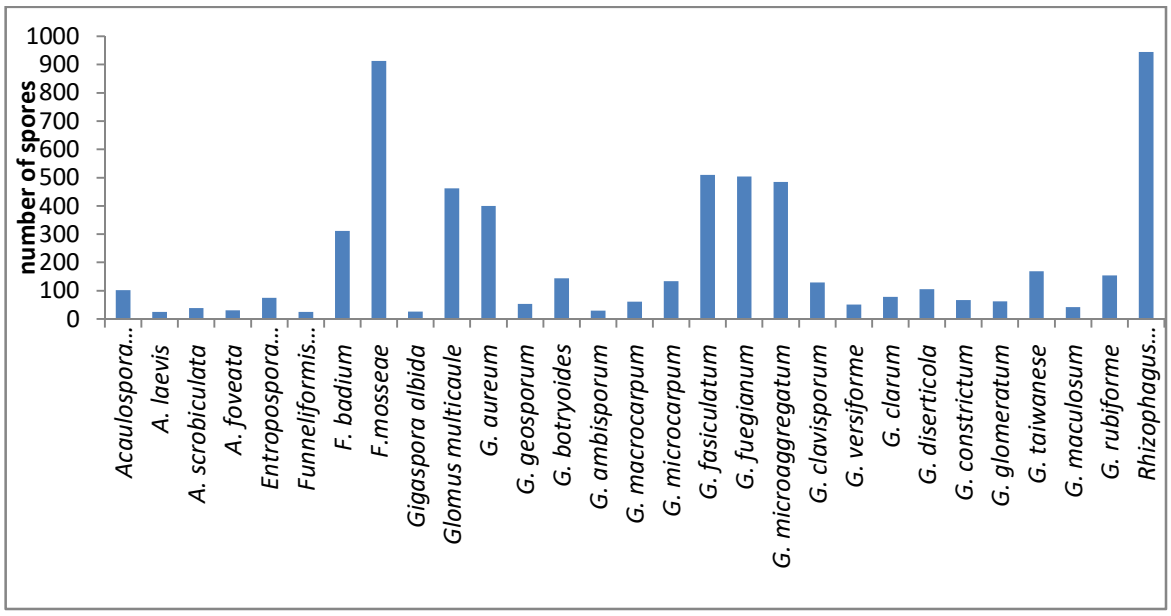


Figure 13: Total number of AMF spores counted from the three study sites.

Among the 29 species recovered from the rhizosphere of banana, there are 6 dominant species. The most frequent species was found to be *Rhizophagus intradices* contributing 15.3% of the whole population followed by *Funneliformis mosseae* 14.9% then *Glomus fasciculatum* 8.3%, *G. fuegianum* 8.2%, *G. microaggregatum 7.9% and Glomus multicaule* 7.5%. Among these dominant species *F.mosseae, R.intradices, G. fuegianum* and *G. fasciculatum* were found to be present in all seasons as well as in all the study sites.These two species were also reported to be dominant in orchard ecosystem in Tamil Nadu (Chandrasekeran and Mahalingam, 2014). *F. Mosseae* are known to be a frequent component of communities of AMF associated with plants of different regions (Blaszkowski *et al*., 2001). *G. fasculatum* indicates that some species are facultative symbionts (Blaszkowski *et al*., 1998). Koske and Gemma (1997) reported that *Acaulospora* species are probably a widely distributed AMF in the world.

Agricultural practices may induce selection pressure in such a way that a certain AMF group could adapt to changes, establish and proliferate better than others (Singh *et al*., 2008). The occurrence of many AM species in a diversity probably related to their edaphic requirements. Several edaphic factors such as pH, soil texture, organic matter, soil moisture and nutrient level were shown to affect

spore germination, root colonization and efficiency of AM fungi (Khalil *et al*., 1992). The dominance of *Glomus* and *Acaulospora* species could be attributed to their smaller size of spores. Small spores are able to distribute and produce a large number of spores in a short time (Hepper, 1984).Beside seasons, the host plants and edaphic factors are also important factors influencing AM fungal spore density and species richness. Factors such as disturbance, sporulation efficiency and dormancy are also known to affect the abundance of spores (Klironomos *et al*., 1993; Hart and Reader, 2004; Voříšková *et al*., 2016). Since AMF form mutualistic associations with plants roots, and only propagate in the presence of plants, they are sensitive to soil disturbance, land management and cropping practices, and they may therefore be an early and sensitive indicator of environmental change and health (Oehl *et al*., 2010). The AMF recovered survived disturbances and known to resistant to adverse environmental conditions and produce large amount of spores during unfavourable conditions.

The important soil physico-chemical properties given in figure 16 were analysed with number of species and number of spores to determine Pearson's correlation between them and showed in table 16. A positive correlation was found between number of species and soil moisture content while number of spores gave a negative correlation with soil moisture content in all the study sites. Temperature was found to have a negative correlation in all the study sites except with number of spores in Y2. A significant negative correlation was found between bulk density and spore population (-0. 825*) while negative correlation was found between bulk density and species richness in Y3. Porosity and pH had a negative correlation with both number of species (-0.219), (-0.412) and number of spores (-0.353), (-0.374) in Y1 respectively while pH also had a negative correlation with number of species (-0.626) in Y3. A positive correlation was found between C and species richness (0.256) in Y2 and number of spores (0.156) in Y3. N had a significant negative correlation with number of spores in Y1 (-0.770*) in Y1 and species richness (-0.875*) in Y3. While a positive correlation was found only with species richness in Y2. P also had a significant correlation with spore population (-0.821*) in Y1 while species richness showed positive correlation in all the study sites. K showed no relation with species in Y1 and population of spore in Y2.

Table 16: Pearson correlation between different soil parameters, number of species and abundance of spores in roots of banana.

Variables	Y1		Y2		Y3	
	species	spores	species	spores	species	spores
SMC	0.453	-0.190	0.625	-0.573	0.342	-0.702
Temp	-0.303	-0.157	-0.418	0.631	-0.300	-0.108
Bd	0.507	0.266	0.468	0.082	-0.702	-0.825*
Porosity	-0.219	-0.353	0.568	0.352	0.223	0.233
pH	-0.412	-0.440	0.408	0.381	-0.626	0.495
C	-0.484	-0.374	0.256	-0.008	-0.311	0.156
N	-0.113	-0.770*	0.288	-0.057	-0.775*	-0.152
P	0.096	-0.821*	0.345	-0.045	0.711	-0.657
K	0.019	-0.514	0.244	0.002	0.197	-0.220

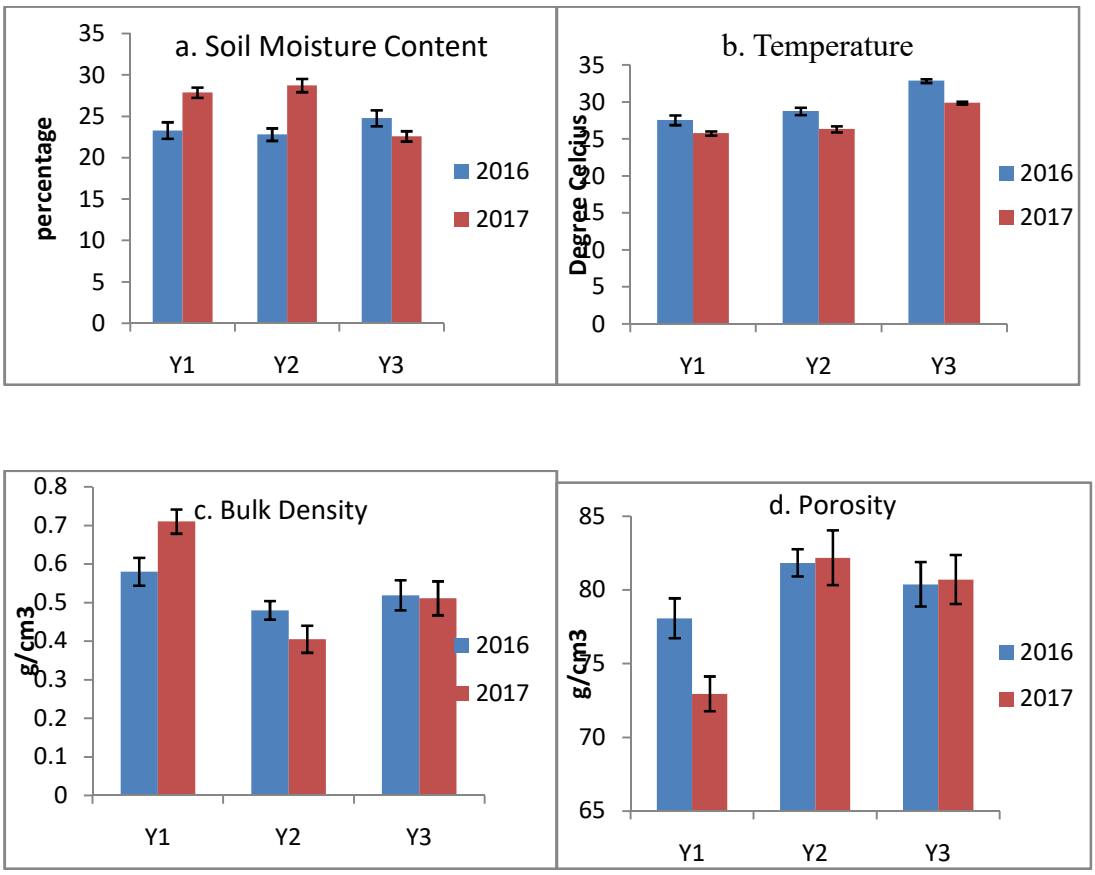
*. Correlation is significant at the 0.05 level (2-tailed).

The result revealed that season played an important role in the fluctuation of different soil parameters irrespective of species richness and population of AMF spores. Edaphic factors have a great influence on AMF development in different hosts which strongly supports the role of soil nutrients for their symbiotic and parasitic functions has been widely reported by many authors (Carrenho *et al*., 2007; Antunes *et al*., 2012; Nouri *et al*., 2014; Vinodkumar *et al*., 2016). High P and N availability is reported to be negatively correlated with AM fungal activity ((Liu *et al*., 2016, Bakhshandeh *et al*., 2017). A negative correlation between P and species richness in jhum land was also reported by Mohammad *et al*. (2003) in his study on the population of arbuscular mycorrhizal fungi in semi-arid environment of Jordan which was influenced by biotic and abiotic factors.

4.8. Soil Physico-chemical Properties in Cowpea

In cowpea, the physical and chemical characteristics of soil in different sites are presented in Figure 14 (a-i). Soil moisture content shows an increase of 23.29%

to 27.83%, 25.85% to 28.73% and 24.78% to 25.59% in Y1, Y2 and Y3 respectively from 2016 to 2017(Fig 14.a). Soil temperature decreases from 2016- 2017 ie., 27.5 to 25.7ºC, 28.76 to 25.77ºC and 32.8 to 29.8ºC in Y1, Y2 and Y3 respectively(Fig 14.b). Y1 had the highest bulk density (fig 14.c) and also the lowest porosity among the three study sites (fig 14.d). The soil is acidic in all the jhum fallows and pH lies between 4.78-5.10 (fig14.e). There was increasing soil organic Cin Y2 (2.07% to 2.26%) and Y3 (2.13% to 2.44%) while decrease in Y1 (1.64% to 1.58%) (fig14.f). Y3 was found to contain highest K among the three study sites having K 356.44 kg/ha in 2016 and 355.6 kg/ha in 2017 (fig 14.i) and N 339.5 kg/ha in 2016 and 343.5 kg/ha in 2017 (fig 14.g).P was found to increase from 11.43kg/ha to 12.92 kg/ha in Y1, 16.54 to 21.13kg/ha in Y2 and 23.08 to 26.33kg/ha in Y3 (fig 14.h).



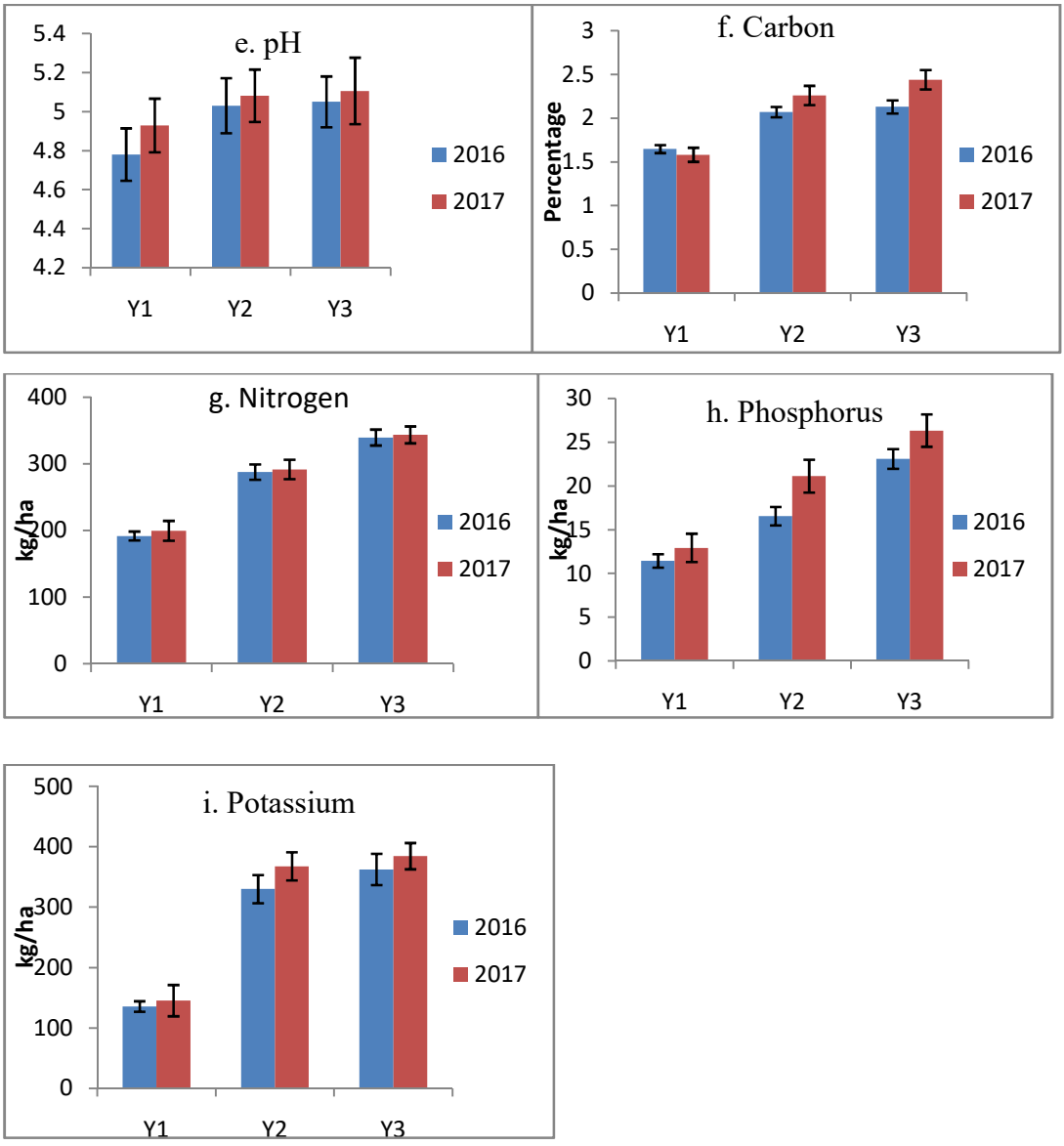


Figure 14 (a-i):Bar chart showing mean values and standard deviation of different soil parameters in cowpea. Bars were ± standard error of the means.

The soil moisture was found to be higher in 2017 than the previous year in all the jhum lands which might be due to increase rainfall. There is also simultaneous decline in the soil temperature from 2016 to 2017 which may be attributed to increase in rainfall and soil moisture. The moisture content was also found to have a positive correlation with AMF colonization in the roots from Pearson's correlation (Table 17). Singh (2001) has also reported that soil moisture plays a significant role on mycorrhizal development and colonization.

The soil of the three different study sites were found to be acidic (Fig 14.e) which might be attributed to deposition of above ground biomass through litter fall and in situ-deposition of grasses which resulted in subsequent enrichment with the bases. Among the three different jhum fallows, Y1 had the most acidic soil which was having the most frequent cycle of jhuming period i.e., 3years which is followed by continuation of human exploitation and intermittent farming. It also has the least content of C, N, P and K compared to the Y2 and Y3(Fig 14.f-i)which is in accordance with Chase and Singh (2014). This might be due to due fast oxidation of soil organic matter, washing away of nutrient rich top soil with runoff water, rapid decomposition, poor recycling back of crop residues, continuous and intensive cultivation of crops without replenishment of nutrients through chemical fertilizers, continuous human intervention, tillage and crop rotation, fire etc., (Chase and Singh, 2014). Continuous cultivation as in shifting cultivation reduces soil organic matter by burning of crop residue and facilitating interactions of physical, chemical and biological soil processes that increases its decomposition rate. Repeated soil disturbances lessened the soil resilience and soil restoration capacity as well. Soils with low fertility restrain plant development thus increase the dependence of plants on mycorrhizal association (Siqueira & Saggin Júnior, 2001). Fungi grow more extensively inside the root to maintain the development and functioning of external hyphae under these circumstances, (Sanders *et al.,* 1977).

It has been reported that the organic C and availability of other major nutrient (N, P and K) contents were decreased by 46-73% in just over a span of 3-4 years from fresh burning. However, with the increase in post burning fallow periods from 3-4 years onward, soils exhibited consistent increase in fertility built up, more particularly in 8-10 years old by 27% increase in organic C and 30-70% increase in macronutrient contents over 3-4 years cycle (Kang *et al.,* 1984; Christanty, 1986; Funakawa *et al*., 1997). This may be the reason why Y1 had least N, P, and K in the soil. However, Y1 had the highest AMF colonization percentage among the three study sites in the year 2016 (Fig. 8) despite containing the lowest soil nutrient among the three study sites. This result showed the potential benefits of AMF to their host plants by withstanding and overcome stress in the soil by maintaining high levels of AM colonization. This result is in accordance with Treseder (2004) and Powers *et al*.

(2005). AMF was reported to increase nodulation and atmospheric N fixation potential in legumes such as cowpea (Turk *et al*., 2008) and improves phosphorous uptake by the plant, which in turn would avail more energy for N fixation by rhizobia. Mycorrhizal colonized roots are highly unlikely to be colonized by other microbes, and their susceptibility to soil-borne pathogens such as phytopathogenic fungi or nematodes is lowered (Selveraj and Chellappan, 2006). Greater root colonization by AMF in acid soils with low P availability was reported by Soedarjo and Habte (1995) and Heijne *et al.* (1996). Very dry soil as in Y3 decrease colonization by AMF (Lodge, 1989; Miller and Bever, 1999; Miller, 2000).

Table 17: Pearson correlation between different soil parameters and association of AMF in roots of Cowpea.

Variables	Y1	Y2	Y3
	Colony	Colony	Colony
SMC	0.197	0.216	0.645
Temp	0.120	0.099	-0.836*
Bd	-0.531	-0.579	-0.054
Porosity	0.531	0.566	0.054
pH	-0.665	0.203	-0.086
C	0.432	-0.293	-0.178
N	-0.312	0.373	-0.751*
P	0.168	-0.461	-0.803*
K	0.072	-0.272	0.496

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

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

Where, No.of spores= abundance of spores, colony = Mycorrhizal Colonization, SMC= Soil Moisture Content, BD= Bulk Density, Temp. = Temperature, C= Organic Carbon, N= Nitrogen, P= Phosphorus, K= Potassium.

Pearson correlation showed a significant negative correlation between soil temperature (-0.836*), N (-0.751*) and P (-0.803*) in Y3 while Y1 and Y2 do not show any significant correlation with any of the soil parameters (Table 17). Soil

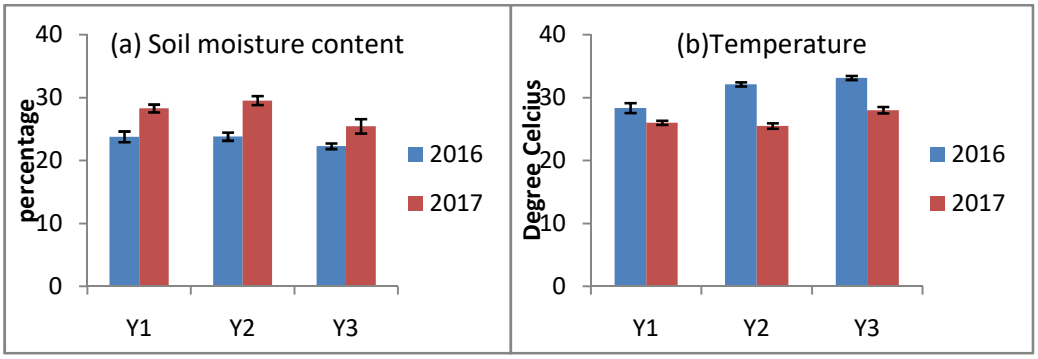
moisture content showed positive correlation with AMF colonization in all the different sites. Temperature showed positive in Y1 (0.120) amd Y2 (0.099). Bulk density was negative and porosity was positive in all the study sites. The soil pH showed negative correlation in Y1 (-0.665) and Y3 (-0.086) while a positive correlation was found in Y2 (0.203). A positive correlation was found between C and AMF colonization in Y1 (0.432) while negative correlation was found in Y2 (-0.293) and Y3 (-0.178). N has a negative correlation with colonization in Y1 (-0.312) and a positive correlation in Y2 (0.373) while P had a positive correlation with colonization in Y1 (0.168) and a negative correlation in Y2 (-0.461). A positive correlation was found between K and Colonization in Y1 (0.072) and Y3 (0.496) while a negative correlation in Y2 (-0.272).

Y2 had the highest colonization among all the study sites in the year 2017 which might be due to the fact that the jhum fallow is left undisturbed. This helps the land to replenish itself with soil minerals. Several workers reported reduction in the rate of host root infection, formation and colonization of VAM fungi from the disturbed site such as Y1 and Y3 (Bellgard, 1993; Miller *et al.*, 1995; Singh *et al*., 2003). The increase in bulk density in Y1 may restrict the growth and movement of propagule in the soil which could result in reducing AM fungi colonization. This could be the reason why Y2 had the highest colonization in the year 2017 among the three study sites. The P content in the soil is lowest in Y1 compared to the other jhum fallows. Pearson's correlation shows a significant negative correlation between P and AMF colonization in Y2 and Y3 which indicates that the higher P content have lower AMF colonization. This is in agreement with reports that plants grown in soils with lower available P had a higher AMF colonization rates (Sang Joon Kim *et al*., 2017). Increases in available soil P levels and related reduced root colonization have also been reported by several workers (Douds and Schenck, 1990; Miller *et al*., 1995; Kahiluoto *et al*., 2001). However, a positive correlation was found between P and AMF colonization in Y1. This could be as the level of available P is not high enough to inhibit the AMF colonization at these sites (Muleta *et al*., 2007). A significant negative correlation found in Y3 between P, N and colonization showed that higher the nutrients in the soil reduce the AMF colony in cowpea. However, the level of

human disturbance in the soil in the form of fire, logging etc in Y3 may also supress the degree of colonization to a large extent.

4.9. Soil Physico-chemical Properties in Maize

In maize, the analysis of the soil physico-chemical properties showed a significant variation between the three different study sites. Soil moisture content shows an increase in Y1, Y2 and Y3 respectively from 2016 to 2017 (fig.15.a) while soil temperature decreases from 2016- 2017 in Y1, Y2 and Y3 respectively (fig.15.b). The bulk density was highest while porosity was lowest in Y1 in both years of 2016 and 2017 respectively (fig. 15.c and fig.15.d). The soil was acidic in all the jhum fallows and lies between pH 4.86 - 5.18 (fig.15.e). There was decrease in soil organic C in the sites Y1 (1.58% to 1.54%) while increase in Y2 (2.0% to 2.24%) and Y3 (2.26% to 2.51%) (fig.15.f). However there was slight increase in N where Y1 had the lowest N content i,e., 190.75 kg/ha and 199.5 kg/ha while Y3 had the highest N content of 339.5 kg/ha and 343.5 kg/ha in 2016 and 2017 respectively (fig.15.g). K content in soil was found to increase from 2016 to 2017. P was found to increase from 11.37 to 12.82 kg/ha in Y1, 16.14 to 20.41 kg/ha in Y2 and 22.92 to 27.32 kg/ha in Y3 (fig.15.h).The highest K content was found in Y3 among the three sites (fig.15.i)



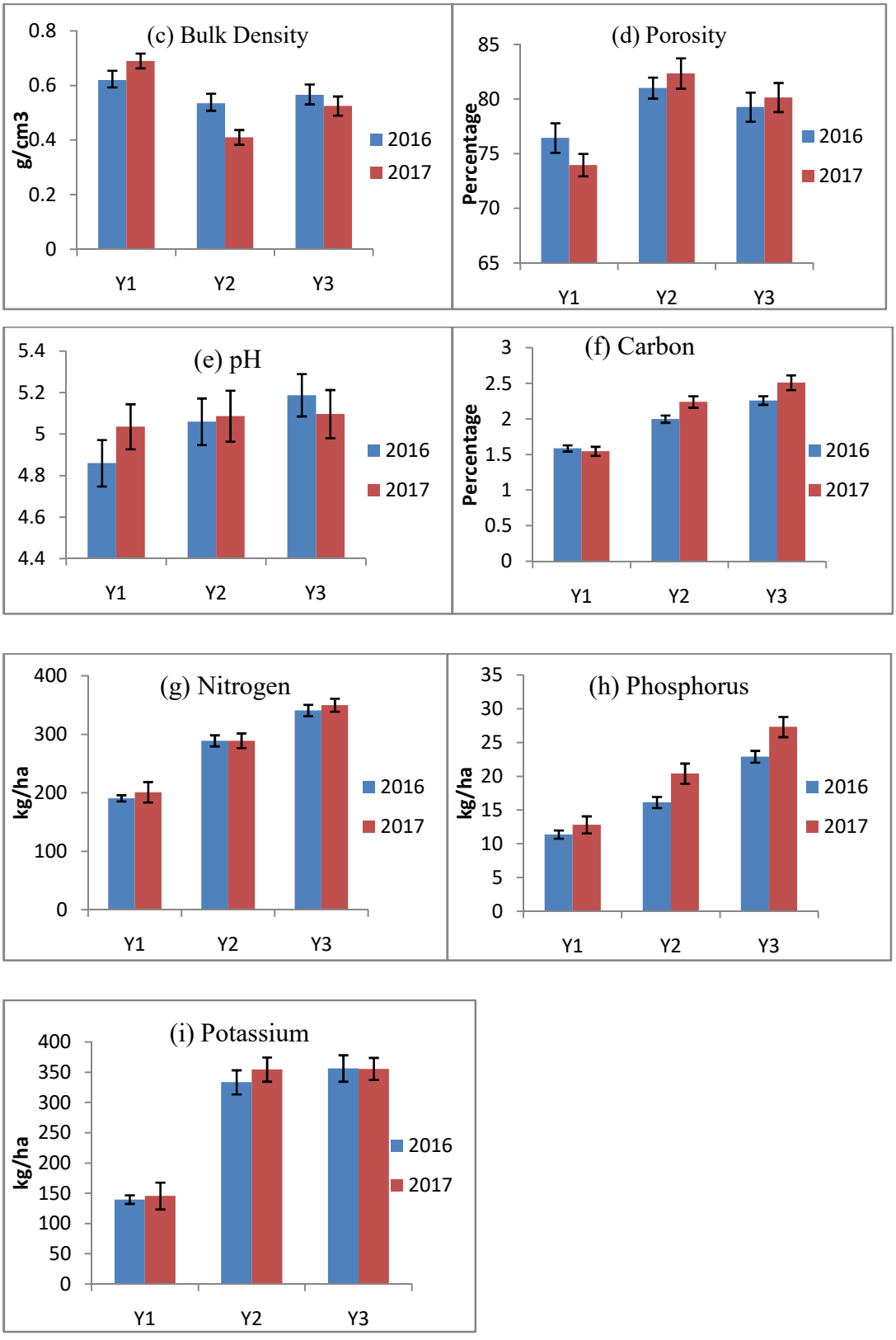


Figure 15(a-i): Bar chart showing mean values and standard deviation of different soil parameters in Maize. Bars were ± standard error of the means.

Edaphic factors or soil nutrient status are claimed to be implicated in the patterns and timing of the development of AM fungi (Mullen and Schmidt, 1993; Sanders, 2002). Here, in this study we found acidic soils from the three sites which might be attributed to deposition of above ground biomass through litter fall and *in situ*-deposition of grasses which resulted in subsequent enrichment with the bases. Y1 had the most acidic soil among the three study sites and comprises the highest AMF colonization among them. In general, slightly acidic soils had significantly greater number of AM propagules, whereas the soils with higher acidic has fewer propagules (Rajeshkumar *et al*., 2013). A positive correlation was found between AMF colonization and pH which was also reported by Chase and Singh (2014).The conversion of natural forest to cultivated land is manifested the most in the on-site loss of soil organic matter causing a reduction in nutrient stock, CEC, and structure stability (Hartemink, 2008).

The soil moisture was found to be higher in 2017 than the previous year in all the jhum lands which might be due to increase rainfall. There is also simultaneous decline in the soil temperature from 2016 to 2017 which may be attributed to increase in rainfall and soil moisture. The moisture content was also found to have a positive correlation with AMF colonization in the roots from Pearson's correlation (Table 18). Singh (2001) has also reported that soil moisture plays a significant role on mycorrhizal development and colonization.

Table18: Pearson correlation between different soil parameters and association of AMF in roots of Maize.

Variables	Y1	Y2	Y3
	Colony	Colony	Colony
SMC	0.660*	-0.310	0.126
Temp	0.028	0.310	-0.344
Bd	-0.180	-0.158	-0.257

Porosity	0.271	0.358	0.133
pH	-0.305	0.089	-0.102
C	0.265	-0.172	0.605*
N	0.538	-0.359	-0.531
P	0.516	-0.174	-0.404
K	0.023	-0.205	0.125

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

Where, No of spores= abundance of spores, Colony = Mycorrhizal Colonization, SMC= Soil Moisture Content, BD= Bulk Density, Temp.= Temperature, C= Organic Carbon, N= Nitrogen, P= Phosphorus, K= Potassium.

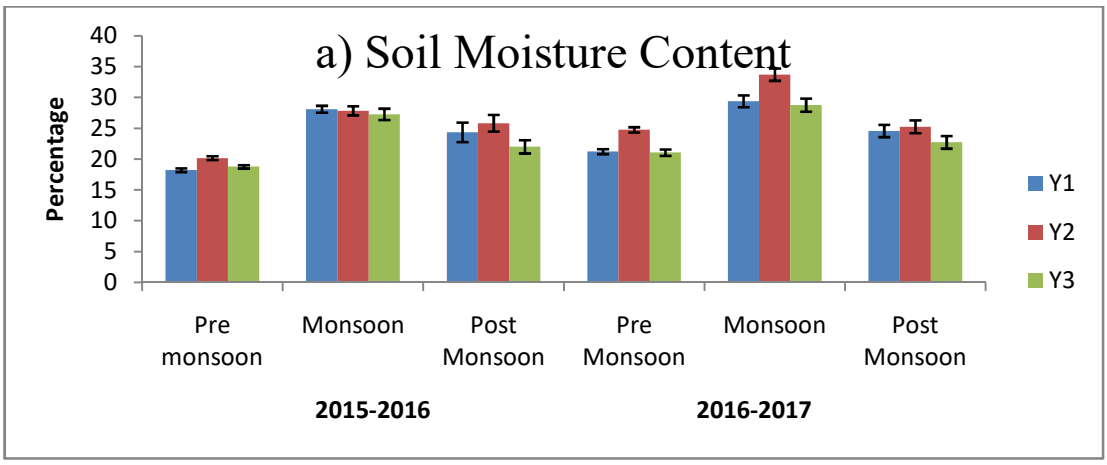
A significant positive correlation was found between colonization in soil moisture content in Y1 (0.660*) and C in Y3 (0.605*). Temperature showed a negative correlation only in Y3 (-0.344). Bulk density was found to have a negative correlation in all the study sites. Y1 has the lowest P content in the soil as compared to the other two sites Y2 and Y3. Pearson's correlation show a negative correlation between AMF colonization against P in Y2 (-0.174) and Y3 (-0.404), while a positive correlation in Y1 (0.516) which indicates that the higher P content have negative influence and show lower AMF colonization. This is in agreement with reports that plants grown in soils with lower available P had a higher AMF colonization rates (Sang Joon Kim *et al*., 2017).

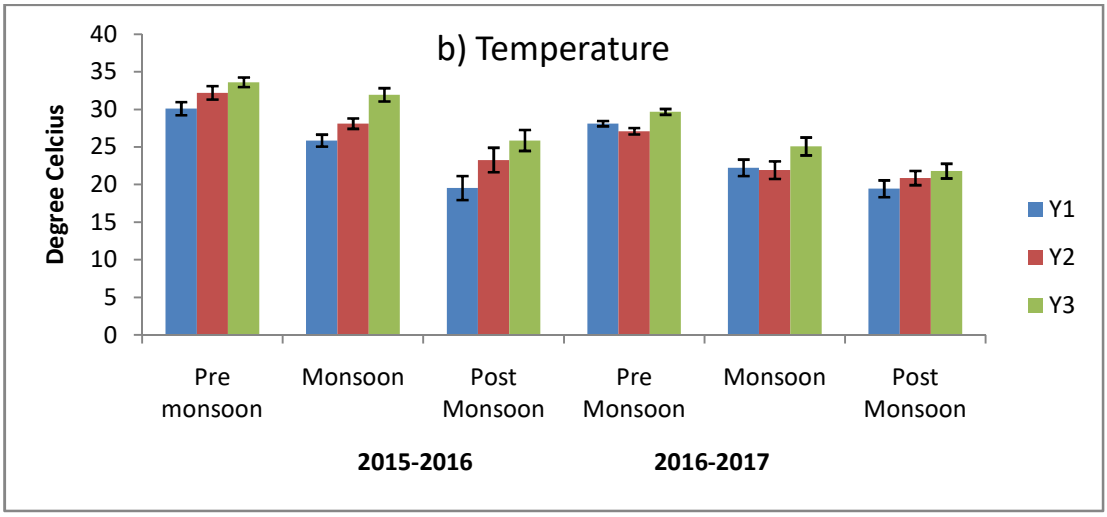
Increases in available soil P levels and related reduced root colonization have also been reported by several workers (Douds and Schenck, 1990; Miller *et al*., 1995; Kahiluoto *et al*., 2001; Verbruggen *et al.,* 2013). When P level is low in soil, the dependence of AMF colonies get higher. The external AMF hyphae extend to soil volumes beyond the depletion zone around the roots (Sanders and Tinker, 1971), and to smaller soil pores and closer to the surfaces of soil particles than do the roots and root hairs (O'Keefe and Sylvia, 1992). A low temperature dramatically restrained AMF colonization was reported by Chen *et al.* (2014). Temperature decreases from 2016 to 2017 which may be the cause to decrease the percentage of colonization in Y1and Y2 as shown in Figure 9. The ability of the AM fungus to spread and form a hyphal network in the substrates was influenced by their physical properties, such as

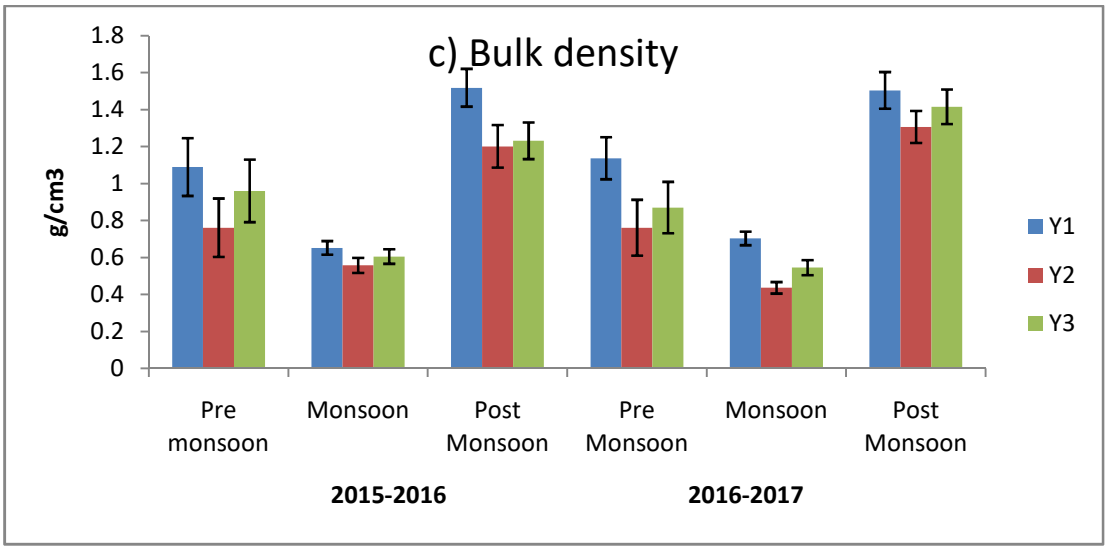
compaction and water retention was reported by Gaur and Adholeya (2000). Reduction of bulk density and increase porosity result in the elongation of the hyphae of the AM fungi and the elongation of the roots (Ezawa *et al*., 2002). Osonubi (1994) suggested that under dry conditions, AMF inoculation enhanced plant growth through the improvement of drought resistance as well as P nutrition in low P soil. However, N also had a negative correlation with colonization in Y2 (-0.174) and Y3 (-.404) and positive correlation in Y1 (0.516). Several reports have been made by some authors (Liu *et al*., 2012; Liu *et al*., 2017 and Kobae *et al*., 2017) suggested that the high amount of N and P level in the soil supress the AMF colonization.

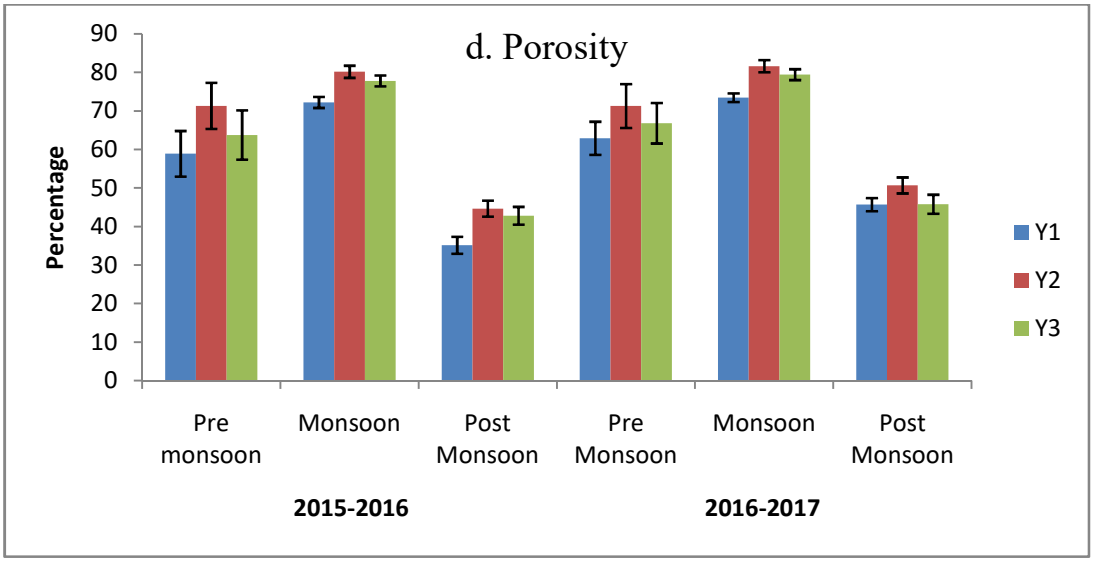
4.10. Soil Physico-chemical Properties in Banana

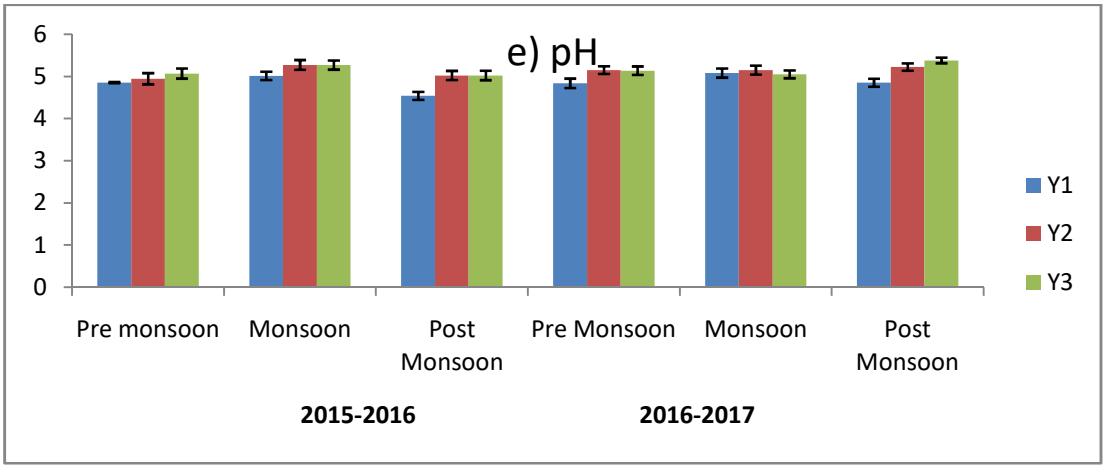
Soil moisture content showed increased from the previous year and highest during monsoon season (fig 16.a) while soil temperature was found to decrease from the previous year and pre-monsoon had the highest among the three different seasons (fig.16.b). Monsoon season was highest in bulk density and lowest in porosity (fig 16.c&d). A most acidic soil was found to be Y3 soil in average in all the seasons from the three different sites (fig 16. e).

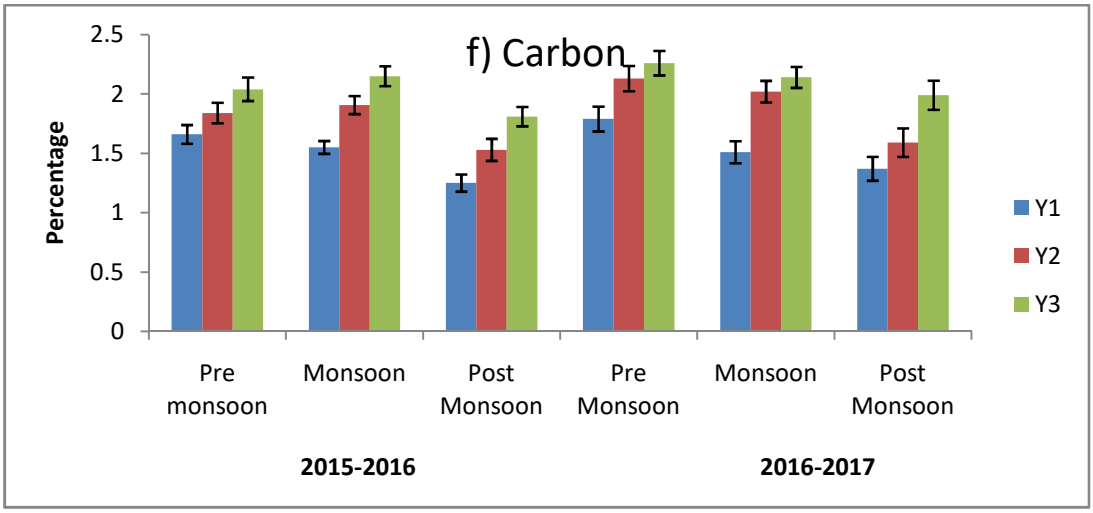


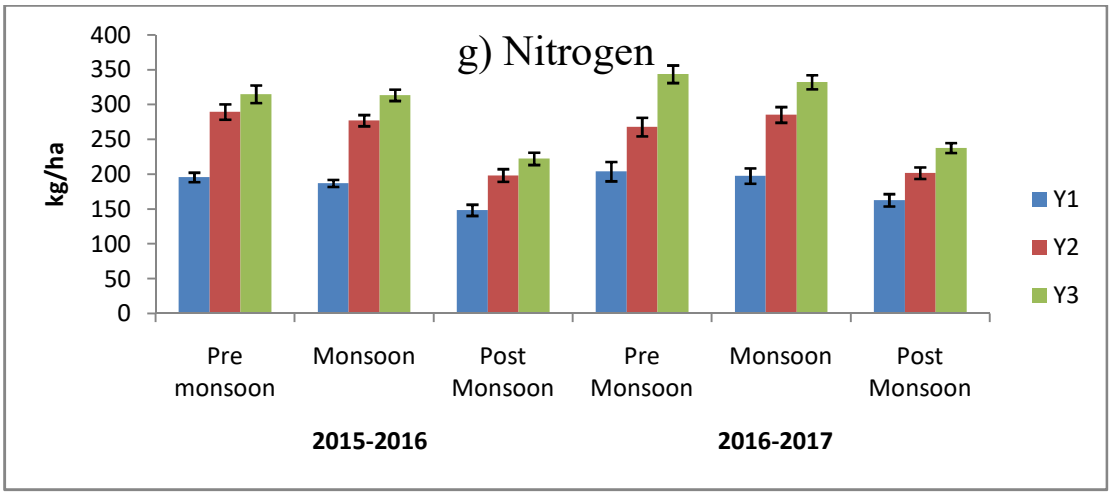

b) Temperature
Degree Celcius
40
35
30
25
20
15
10
5
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3

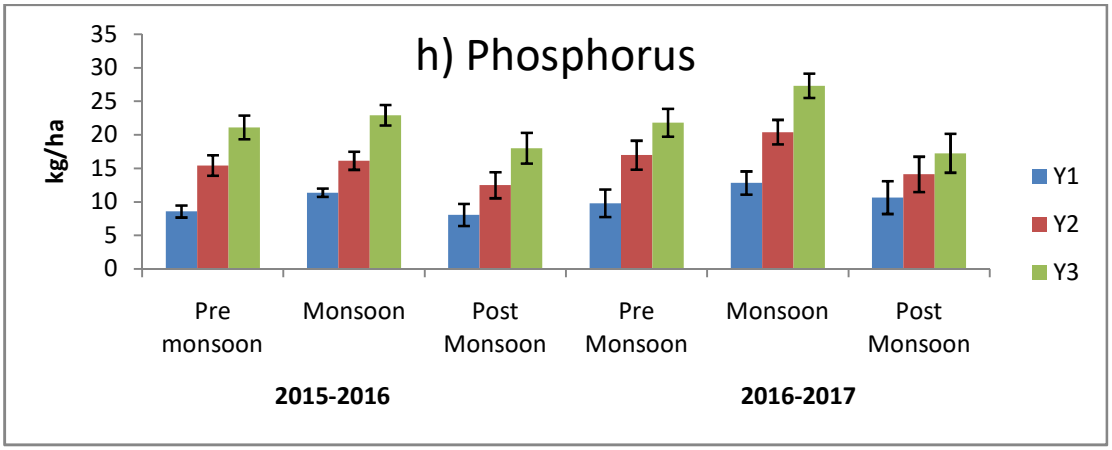

c) Bulk density
g/cm3
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3


d. Porosity
Percentage
90
80
70
60
50
40
30
20
10
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3


e) pH
6
5
4
3
2
1
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3


f) Carbon
Percentage
2.5
2
1.5
1
0.5
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3


g) Nitrogen
kg/ha
400
350
300
250
200
150
100
50
0
Pre monsoon
Monsoon
Post Monsoon
Pre Monsoon
Monsoon
Post Monsoon
2015-2016
2016-2017
Y1
Y2
Y3



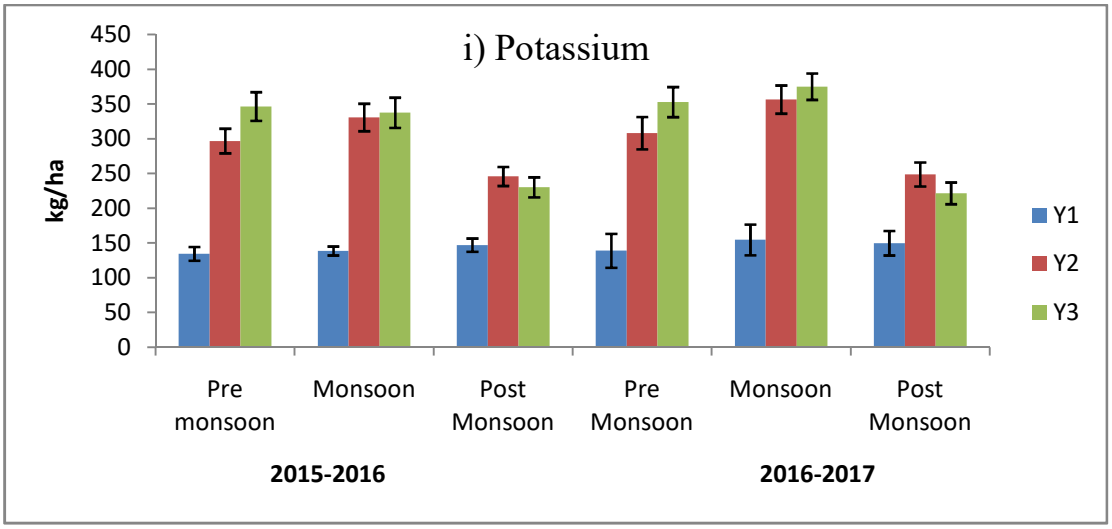


Figure 16(a-i): Bar chart showing mean values and standard deviation of different soil parameters for pre-monsoon, monsoon and post-monsoon season of banana. Bars were ± standard error of the means.

The amount of soil organic Cand K were found to be much equal throughout the whole years of different seasons while Y3 has got the highest content among the different jhum lands Y1, Y2 and Y3 (fig 16. f and h). While the least amount of N and P was found during post monsoon season (fig 16. g and i). Organic C, P and K were found to be highest during monsoon season while N was highest during pre-monsoon season. Unlike P, N, especially in its anionic form nitrate (NO3-) is mobile in the soil solution and therefore subject to leaching.

Soil moisture was highest during monsoon season which may be attributed to heavy rainfall during this season. Decline in soil temperature from 2016 to 2017

could also be due to increase rainfall from the previous year. It was observed that there was a decline in colonization from Y2 to Y1 then Y3. This can be due to pH and soil moisture content of the soil. Spore germination and root colonization of AMF are suppressed in acidic and alkaline soils (Isobe *et al*., 2007). Variations in soil pH may alter the concentration of many nutrients and toxic ions in the soil and thereby affect the development and function of AM fungi. Another reason for decreased VAM populations and species diversity in the jhum fallow site could be that the fungal propagules were killed as a result of uncontrolled burning of dried slash on the soil surface during the preparation of field for cultivation of crops. High amount of soil nutrients and regular disturbances due to human intervention could be attributed to the reason why AMF colonization was low in Y3. High amount of nutrients in the soil reduce the dependence of AMF thus supress the formation and development of AMF in the rhizosphere (Grant *et al*., 2005). In Higher plant tissue having P concentration; plants tend to reduce root exudation such as of strigolactones (a group of apocarotenoids) that act as signal molecules for spore germination and hyphal branching of AMF. Reduced exudation results then in low AMF colonization and spore production (Schwab *et al*., 1991; Akiyama *et al.,* 2005; López-Ráez *et al.,* 2008 and Garcia-Garrido *et al*., 2009).

Table 19: Pearson correlation between different soil parameters and association of AMF in roots of Banana.

Variables	Y1 Colony	Y2 Colony	Y3 Colony
SMC	0.710	0.199	0.895*
Temp	0.082	0.512	-0.496
Bd	-0.232	0.013	0.588
Porosity	-0.307	-0.332	-0.295
pH	-0.013	0.250	-0.091

C	0.860*	0.062	-0.314
N	0.173	0.017	-0.620
P	-0.256	-0.345	-0.922*
K	-0.135	-0.016	-0.107

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

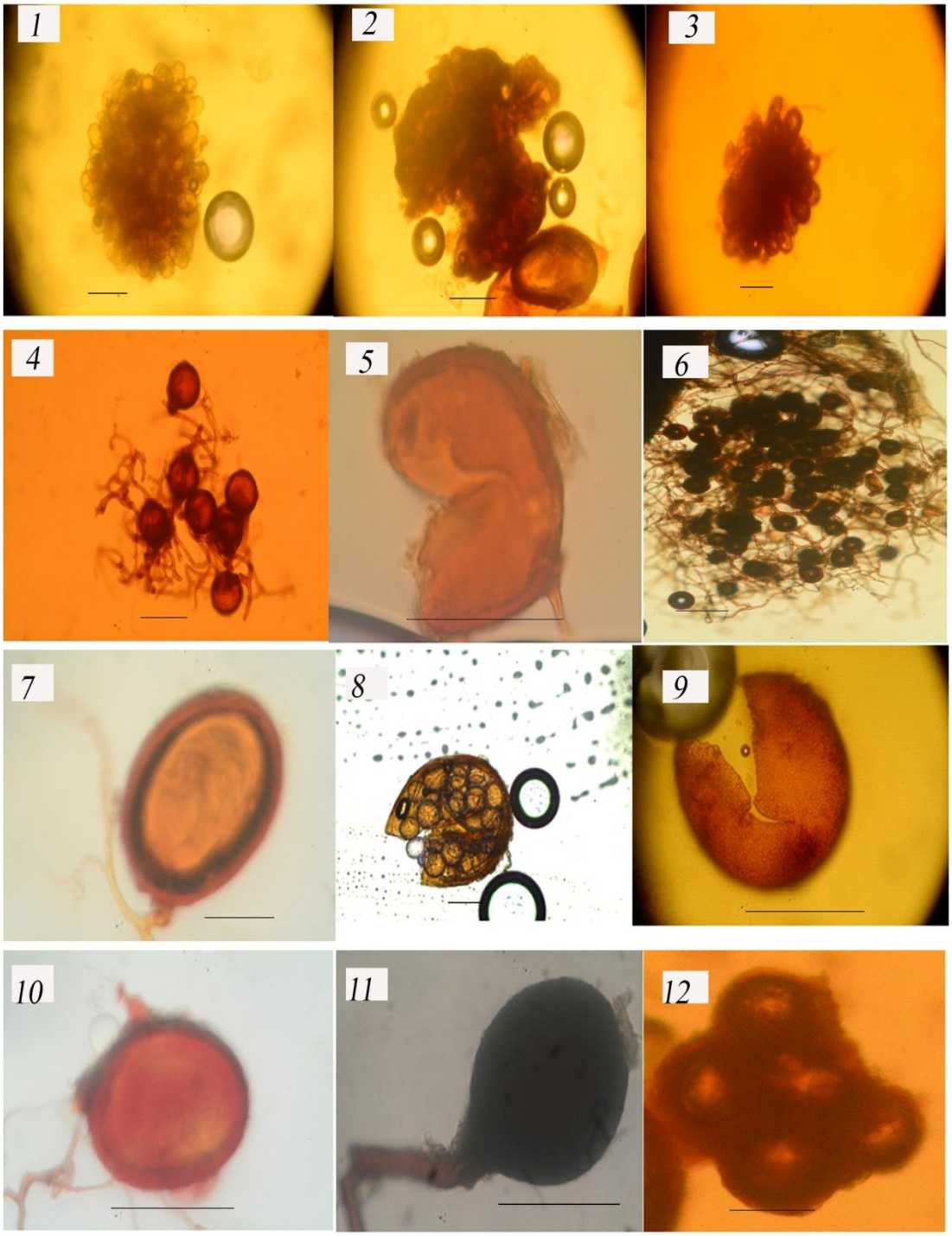
**. Correlation is significant at the 0.01 level (2-tailed).

Where, colony = Mycorrhizal Colonization, SMC= Soil Moisture Content, BD= Bulk Density, Temp.= Temperature, C= Organic Carbon, N= Nitrogen, P= Phosphorus, K= Potassium.

A significant negative correlation was found between P and colonization in Y3 (-0.922*) while a positive significant correlation shown by soil moisture content (0.895*) in Y3 and organic C in Y1 (0.860*). AMF colonization also showed negative correlation with soil temperature (-0.496) in Y3, bulk density (-0.232) in Y1, porosity in all the study sites, pH in Y1 (-0.013) and Y3 (-0.091), organic C in Y3 (-0.314), N in Y3 (-0.620) and P and K in all the study sites. The negative correlation between AMF colonization with N and between P and number of spores is in accordance with the report of Singh *et al*. (2003) in jhum lands. In contrast to the present results in Y1 and Y3, a positive correlation between pH and root colonization was reported by Akond *et al*. (2008) in Bangladesh. In this study, soil moisture and AM fungal colonization were positively correlated, which is in agreement with Bhardwaj and Chandra(2018). These results suggested that the percentage of colonization and the number of AMF spores were largely influenced by the conditions of soil. Soil moisture, pH and available nutrients (N and P) had varied influence on AM fungal colonization and spore number (Khanam *et al*., 2006). Because of nitrate mobility the mycorrhizal symbiosis may not be important for the uptake of mineral N by the host plant. However, under N deficient 4 conditions, growth of fungal hyphae in organic patches may be an effective way of supplying N to both the fungus and the host plant (Hodge *et al*., 2001; Leigh *et al*., 2009; Hodge

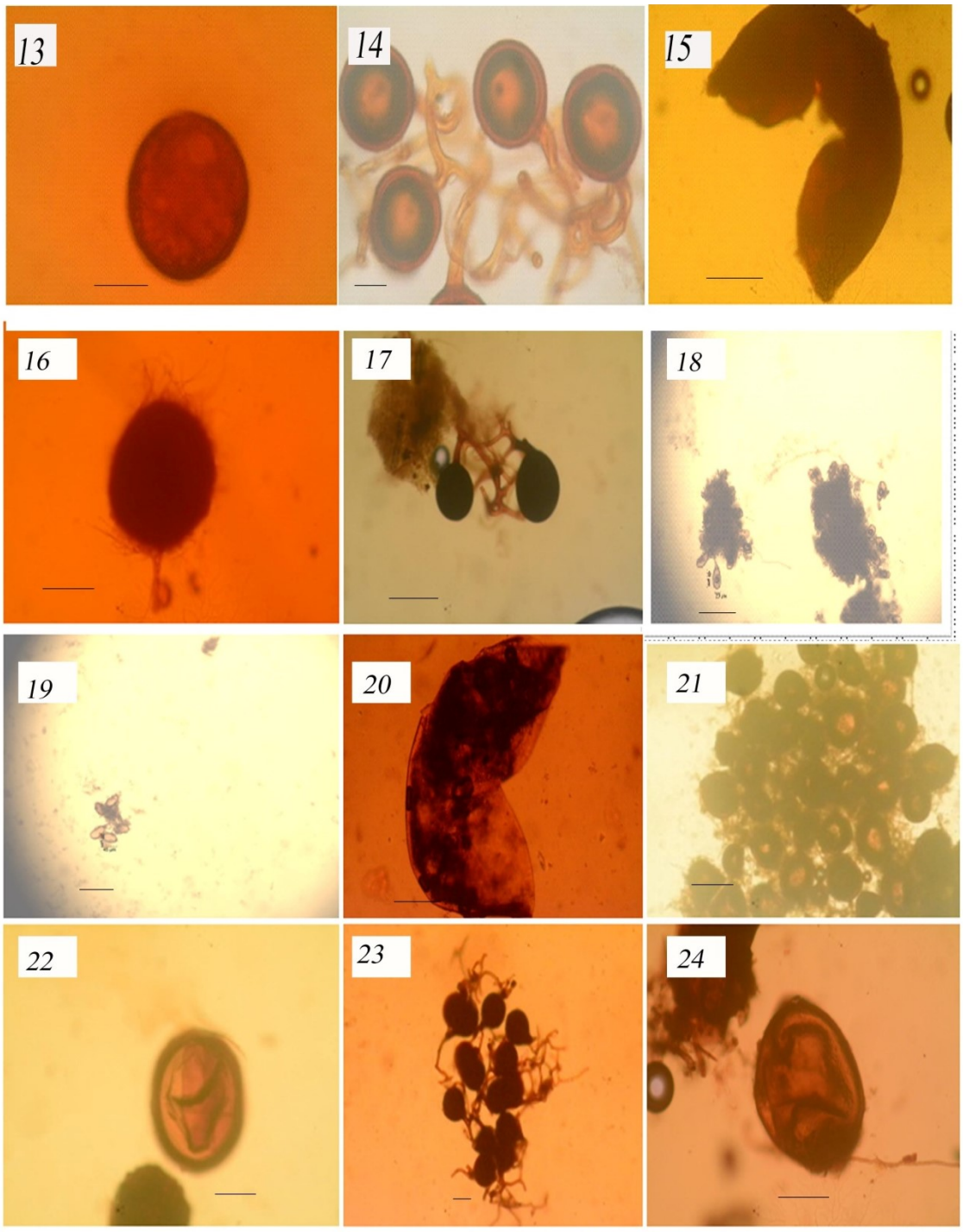
and Fitter, 2010). However, other aspects like climate changes due to seasonal fluctuations may also affect the AMF colonization in plants. Changes in soil temperature, soil moisture content and pH were reported to affect the AM colonization and some fungi may become active at times of year when they are currently dormant or they might response to disturbance at a different rate (Fitter *et al*., 2000).

Photo plate:1



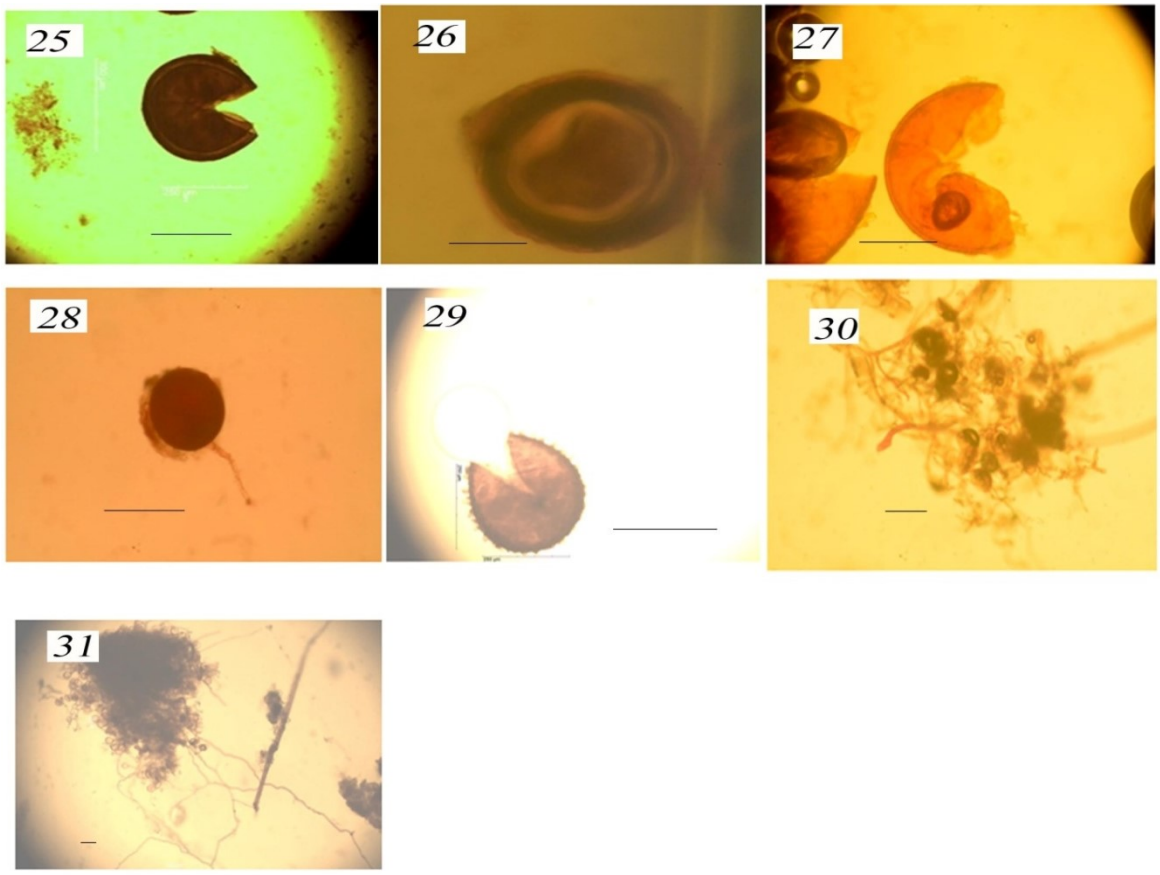
1. *Glomus aureum*. Bar scale=100µm. 2. *G. clavisporum*. Bar scale=100µm 3. *G. fuegianum* Bar scale=100µm 4. *G. glomeratum* Bar scale= 100µm 5. *G. macrocarpum* Bar scale=100µm 6. *G. microaggregatum*Bar scale= 100µm 7. *G. deserticola* Bar scale= 100µm 8. *G. versiforme* Bar scale= 50µm 9. *G. clarum* Bar scale= 300µm 10. *G. multicaule* Bar scale= 200µm 11. *G. geosporum* Bar scale= 100µm 12. *G. ambisporum* Bar scale=50µm

Photo plate:2



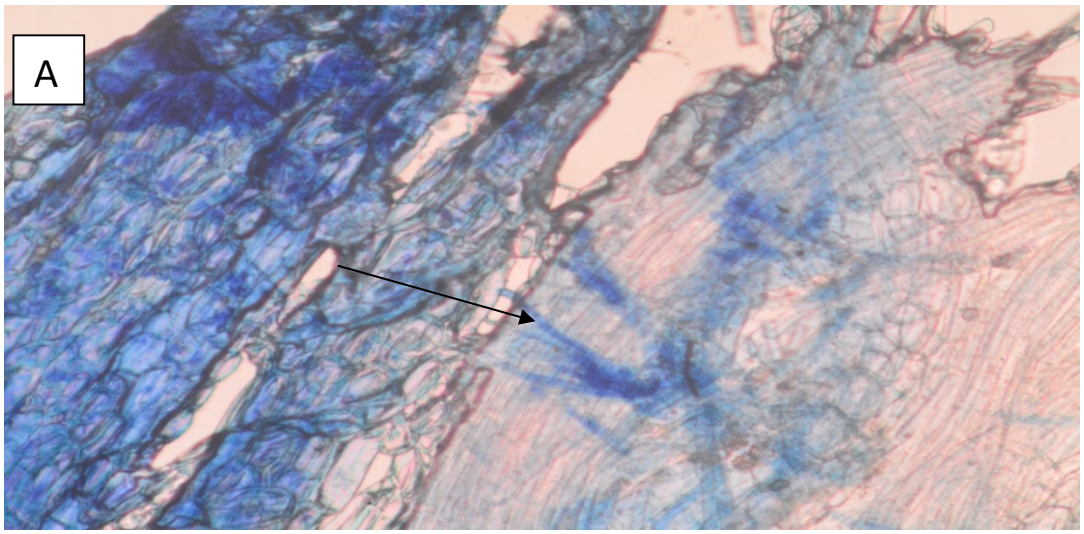
13. *G. microcarpum* Bar scale=50µm 14. *G. fasciculatum* Bar scale=50µm 15. *G. constrictum*Bar scale=50µm 16. *G. verruculosum* Bar scale=50µm 17. *G. botryoides* Bar scale=100µm 18. *G. Taiwannese* Bar scale=100µm 19. *G. rubiforme* Bar scale= 100µm 20. *G. maculosum* Bar scale=50µm 21.*Funneliformis mosseae* Bar scale=100µm 22. *F. coronatum* Bar scale=100µm 23. *F. badium* Bar scale=50µm 24. *Acaulospora scrobiculata* Bar scale=200µm

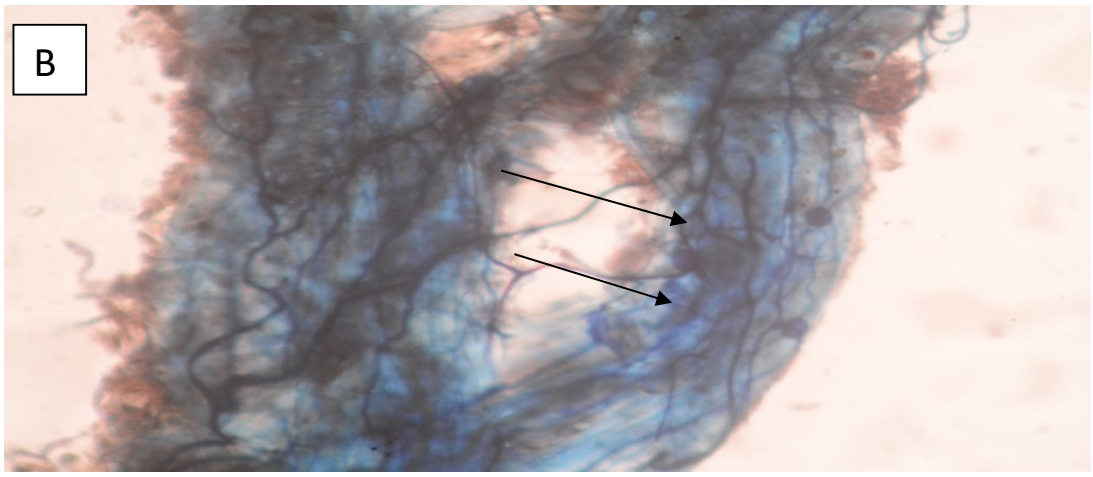
Photo plate:3

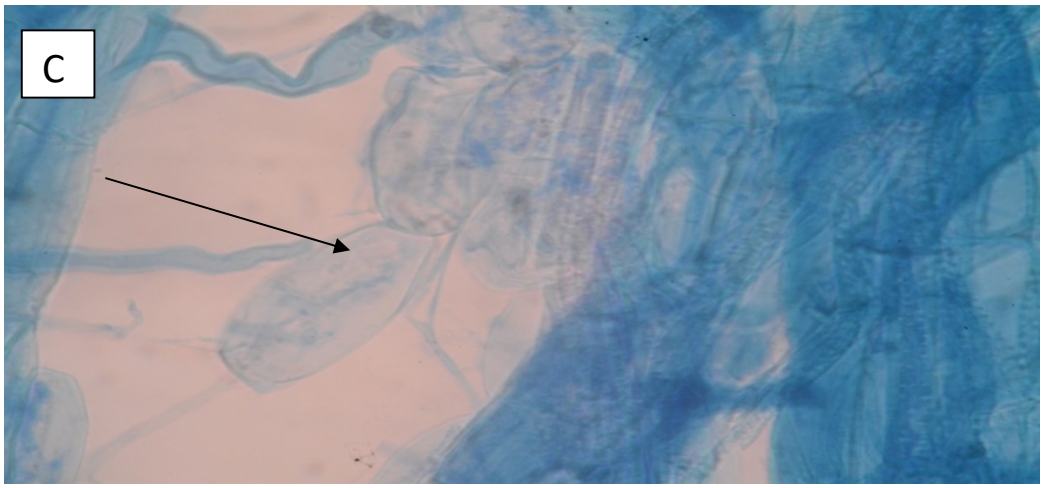


25. *A. tuberculata* Bar scale= 50µm 26. *A. laevis* Bar scale= 50µm 27. A. foveata Bar scale= 200µm 28. *Gigaspora margarita* Bar scale=50µm 29. *G. albida* Bar scale= 200µm 30. *Entrophosphora schenkii* Bar scale= 100µm 31. *Rhizophagus intradices* Bar scale= 50µm.

Photoplate:4

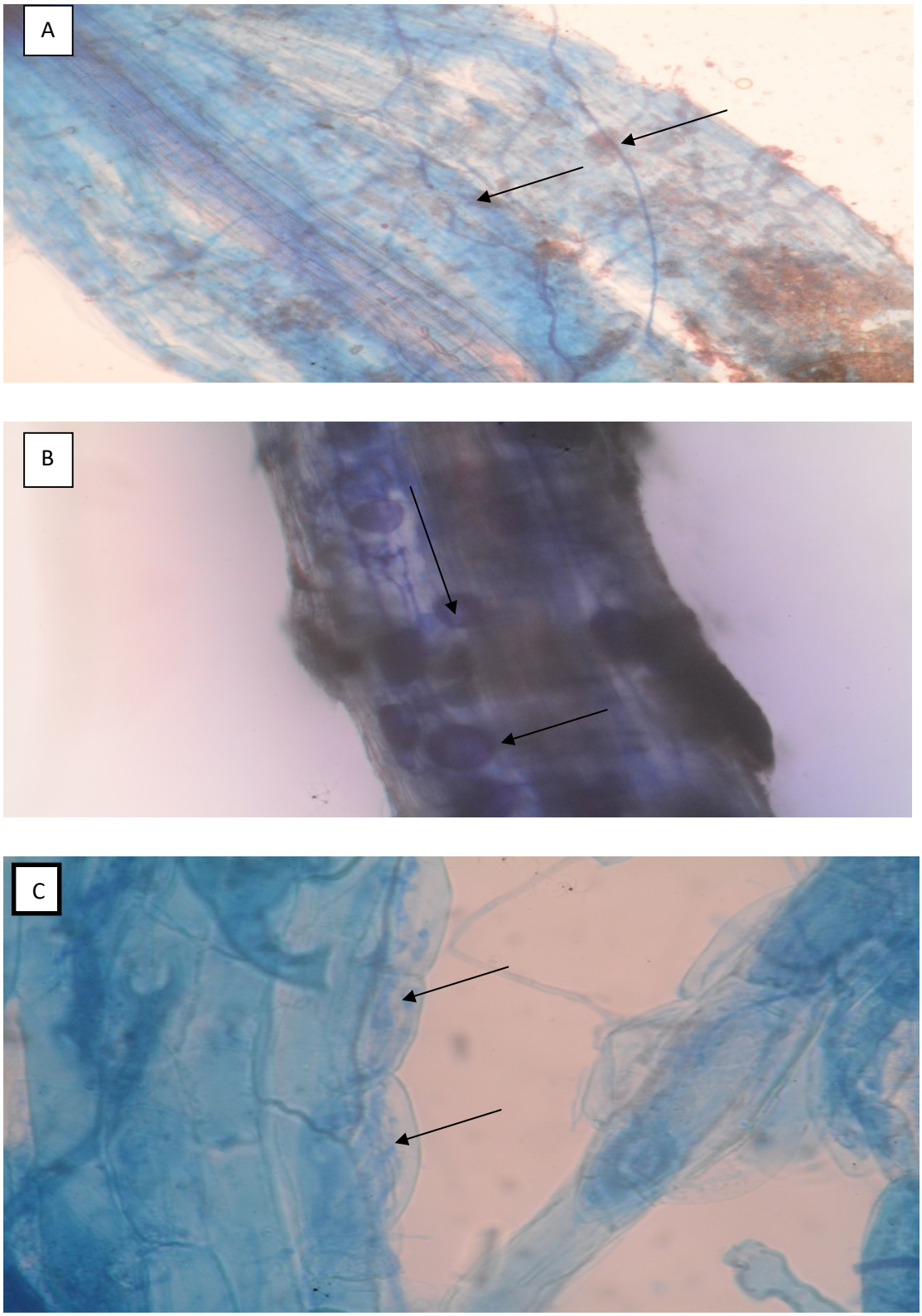






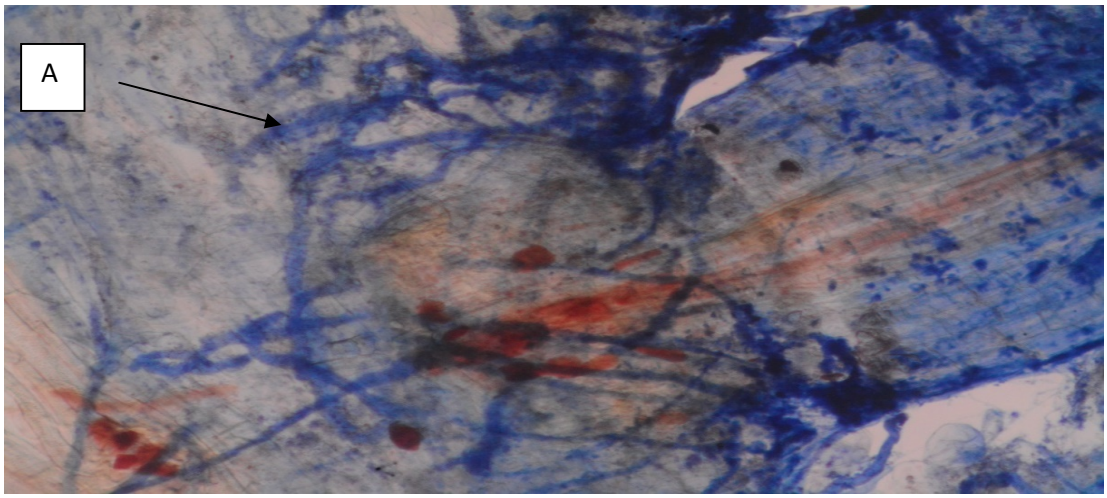
A. Fungal hyphae. B. Vesicles. C. Arbuscles in Cowpea.

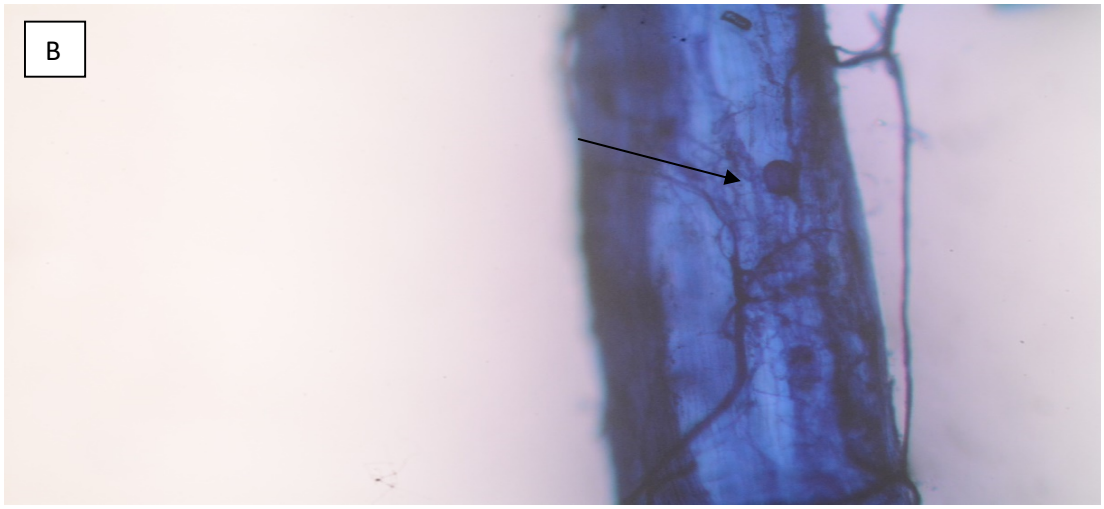
Photoplate: 5

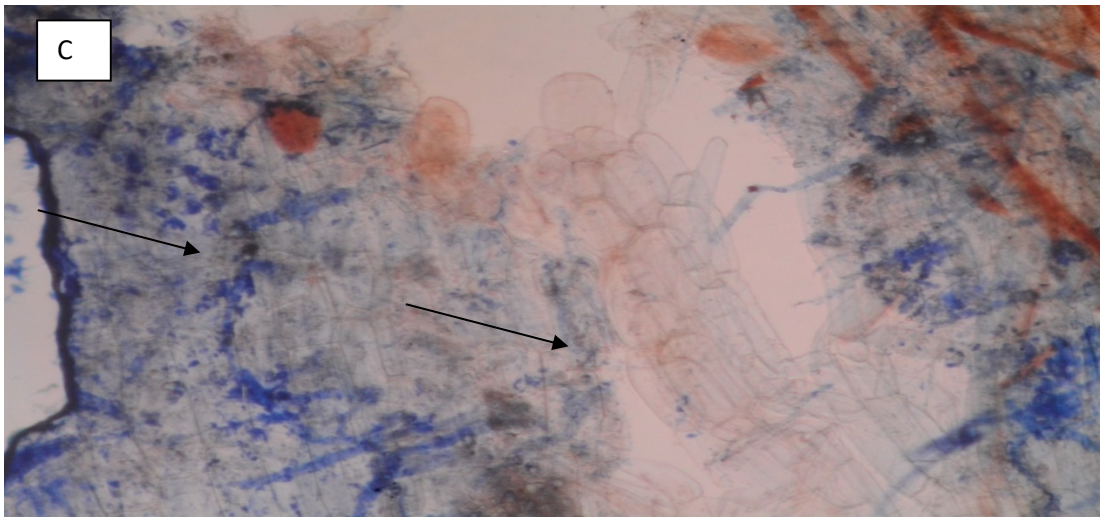


A. Fungal hyphae. B. Vesicles. C. Arbuscles in Maize.

Photoplate:6







A. Fungal hyphae. B. Vesicles. C. Arbuscles in Banana.

The study on AM Fungi communities was done in three different jhum lands which are different in ages of fallows i.e., 3yrs, 6 yrs and 10yrs referred as Y1, Y2 and Y3 respectively. These jhum fallow sites are situated in different locations in Muallungthu, Aizawl District, Mizoram, India as already mentioned in study sites. The composition of soil as well as the association between AMF and their host plants was found to be different in all the different study sites.

Collection of soil samples and specimens was done between 10^{th} to 15^{th} of every month from October 2015 to December 2017. The selected crops are maize, cowpea and banana. Study was made according to the life cycle of selected plants. For maize and cowpea, AMF association and diversity study was done during their life cycle i.e., May to August 2016 and 2017 for maize and May to July 2016 and 2017 for cowpea. Since banana is a perennial herbaceous crop, AMF association and diversity study was done through seasonal basis for two years.

For taxonomical study, the AMF spores were recovered from the soil using wet-sieving and decanting method (Gerdemann and Nicolson, 1963). The isolated spores were mounted with Melzer's reagent and observed under the microscope. The complete and broken spores were examined using a compound microscope with a transmitted light illumination. All the spores were photographed with the help of Moticam 2 camera attached to microscope. Taxonomic identification of spores to species level was based on sporocarpic size, colour, ornamentation and wall characteristics by matching original descriptions in INVAM and other available publications. 31 species belong to 6 genera were identified. Out of 31 species, 20 belong to *Glomus* species, 4 species belongs to *Acaulospora*, 3 species belongs to *Funneliformis*. Only 2 species of *Gigaspora*, 1 species of *Entrophosphora* and 1 species of *Rhizophagus* were identified. A number of spores were also left unidentified due to lack of possible similar records.

For AM fungal association in the selected plants, study was conducted during their life cycle as well as seasonal. Soil samples were taken from the rhizosphere from all the study sites to study the different parameters of soil. The fine roots were

also collected from the selected plants to study association between AM fungi and their host plants.

For association of AMF in Cowpea, the highest colonization percentage was found in Y2 in the month of May 2016 i.e., 60% while the lowest 29% was found in Y3 in the month of July, 2016. By taking the average AM colonization percentage, Y2 had the highest percentage having 51.5% followed by Y1 with 51% and Y3 had the lowest with 41.5%. A one way ANOVA between different ages of jhum on AMF colonization in cowpea show a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 3.357$, $p=0.000<0.05$. Post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2, $p= 0.855>0.05$, while a statistical difference was in Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.009< 0.05$ in the year 2016. There was also no statistical difference between Y1 & Y2, $p= .986>0.05$ however, there was a statistical difference between Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.001< 0.05$ in the year 2017. Pearson correlation showed a significant negative correlation between soil temperature (-0.836*), N (-0.751*) and P (-0.803*) in Y3 while Y1 and Y2 do not show any significant correlation with any of the soil parameters.

For association of AMF in Maize, the AM colonization was found to be highest in Y1 51.75% and 54.25% and lowest in Y3 39% and 42% during 2016 and 2017 respectively. A statistical analysis between the three jhum lands with percentage colonization in the host plant shows a significant variation. A one way ANOVA between different ages of jhum on AMF colonization in maize show a significant effect of jhum on AMF colonization $p< 0.05$ level for the three treatment i.e. $F (5, 71) = 5.856$, $p = 0.000<0.05$. Post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2 ($p= 0.982>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.017< 0.05$) and Y1 & Y3 ($p=0.001< 0.05$) in the year 2016. There was no statistical difference between Y1 & Y2 ($p= 0.732>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.000< 0.05$) and Y1 & Y3 ($p=0.007< 0.05$) in 2017. A significant positive correlation was found between colonization in soil moisture content in Y1 (0.660*) and organic C in Y3 (0.605*). Pearson's correlation show a negative correlation

between AMF colonization against P in Y2 (-0.174) and Y3 (-0.404), while a positive correlation in Y1 (0.516) which indicates that the higher P content have negative influence and show lower AMF colonization.

A correlation a between different soil parameters and AM colonization also showed a significant results which means the ages of jhum fallows affect the soil parameters which inturn effect the AMF colonization in cowpea and maize. The percentage colonization was found to be highest during their juvenile stage and start declining as they become adult and senescence. From the soil parameters studied, it is found that Y1 contain lowest soil nutrients among the three study sites yet having almost same AM colonization percentage in cowpea and highest AM colonization in maize. Several authors reports the benefits of AMF in plants as offering resistance to drought and salinity (Jeffries, 1987), nutrient transfer (Jakobsen *et al.,* 1992; Philips and Hayman, 1970; Smith and Read, 1997), soil aggregation (Rillig *et al*., 2002), improvement of tolerance to drought and salinity (Al Karaki*et al.*, 2004) and plant protection against pathogens (St-Arnaud *et al*., 1995; Jaizme-Vega *et al*., 1997; Habte *et al*., 1999; Jaiti *et al*., 2007) etc. By considering the soil conditions in Y1, it can be said that AMF are an important soil micro-organism which helps their host plants to survive under bad soil conditions. The soil conditions and the environment in Y2 were favourable for AM colonization which is the reason why the colonization percentage was high in this study site. There has been a report that the percentage of colonization was higher in bad soil condition than a favourable condition to help host plants survive by producing higher level of AM colonization to overcome stress soil condition (Treseder, 2004). In the meantime, several edaphic factors were also found to influence the percentage colonization such as temperature and disturbance of soil that often happen in Y3. A regular disturbance and high soil temperature may suppress the AM colonization in Y3 leading to have the lowest colonization percentage among the three study sites.

For AMF association in Banana, the study was conducted in a seasonal basis as they are perennial plants. Colonization of AMF was found highest during monsoon season and lowest during post monsoon season. Y2 had the highest colonization percentage among the three study sites. Humid and warm climate could

favour the colonization which resulted to increase the colonization percentage during monsoon season while soil temperature can be as low as below 10°C during post monsoon season. The low soil temperature may supress the formation of colonization causing to decrease the percentage during post monsoon season. A seasonal influence on the colonization can be clearly seen through the results. A one way ANOVA conducted between AMF colonization and different ages of jhum lands during different seasons showed a significant variation $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 7.217$, $p=0.000<0.05$ for pre-monsoon, $F (5, 71) = 16.214$, $p=0.000<0.05$ for monsoon and $F (5, 71) = 2.557$, $p=0.003<0.05$ for post-monsoon season.A Pearson's correlation between different soil parameter and AMF colonization in the different study sites showed a significant negative correlation was found between P and colonization in Y3 (-0.922*) while a positive significant correlation shown by soil moisture content (0.895*) in Y3 and C in Y1 (0.860*). AMF colonization also showed negative correlation with soil temperature (-0.496) in Y3, bulk density (-0.232) in Y1, porosity in all the study sites, pH in Y1 (-0.013) and Y3 (-0.091), organic C in Y3 (-0.314), N in Y3 (-0.620) and P and K in all the study sites. This shows that different seasons affect the soil properties in all the study sites which inturn affect the AMF association with the host plants. Changes in soil temperature, soil moisture content and pH were reported to affect the AM colonization. Some fungi may become active at times of year when they are currently dormant or they might response to disturbance at a different rate (Fitter *et al*., 2000). Further research is needed to determine whether the seasonal patterns of AMF colonization observed in this study was caused by different site variations among jhum field or the plant type response in which banana was studied here. It can be concluded that learning more about the ecology and intricacies of the AMF association is crucial for attaining a good understanding of AMF formation and functioning in different crop fields and cropping sites in Mizoram with varying edaphic climatic conditions.

For diversity in Cowpea and Maize, the recovered spores are counted with the help of microscope attached with camera to study spore population and species richness. Several diversity indices were conducted viz., Margalef's species richness

index, Simpson dominance index, Shannon Weaver diversity index and Pielou's Evenness index. Species richness and population was highest in Y2 in both cowpea and maize. Because this study site is left abandoned without any disturbances, it may allow certain species to thrive well which we do not found in a disturb area.

For Cowpea, the number of spores was found to be highest in Y2 (515) and lowest in Y3 (475). *Funneliformis mosseae* (formerly *Glomus mosseae*) was the most abundant AMF species recovered from cowpea contributing 24.5% of the whole AMF population while *Rhizophagus intradices (*formerly *Glomus intradices)* came in second with 19.6% and third was *Glomus fasciculatum* contributing 22.3% of the population.The total number of species identified from the rhizosphere was 15 belonging to 5 genera. 12 species were found to occur in Y1 and Y3 while 13 numbers of species was found in Y2. The Simpson dominance index showed a high dominance in Y3 as compared to Y1 and Y2. Pielou's evenness index E showed a lowest in Y1 in 2016 which determines the lowest uniform distribution and highest in Y2 in the year 2017 which indicating that the distribution of AMF is uniformed in this study sites. Shannon Weaver index of diversity was found to be lowest in Y3 (2017) and highest in Y2 (2017). Increase in diversity was found from 2016 and 2017 except in Y3. A one way ANOVA showed no significant variation between different ages of jhum lands and number of spores ($r=.374$; $p>.05$) while a one way ANOVA conducted between the different ages of jhum lands and species richness showed a significant variation $r=.016$; $p<0.05$. A negative significant correlation (-0.922**) was found between species diversity and soil moisture content in Y2.A significant negative correlation was also found between N and number of spores (-0.863*) in Y3 while no significant negative correlation was found with P while it showed negative correlation with both species richness and spore population in all the sites except in Y3 where species richness show a positive correlation (0.083). K was found to have a significant negative correlation (-0.816*) with species richness in Y2.

For Maize, Y2 had the most abundance spore while Y3 had the least AMF spore abundance among the three different studied jhum lands. Two species were found to be dominant in Y1 – *Rhizophagus intradices* and *Funneliformis mosseae* which account for 53.9% of the total spores counted. *Glomus fasciculatum, G.*

fuegianum, G, microaggregatum, Rhizophagus intradices and Funneliformis mosseae were the dominant species in Y2 contributing more than 85% of total AMF spores while *G. fasciculatum, G. fuegianum, R. intradices and F. Mosseae* were the dominant species in Y3 which contribute more than 60% of the total spores counted. A total of 15 species were recovered from Maize belonging 5 genera. Y2 has got the highest diversity as analysed by Shannon diversity index containing 14 and 15 different species in the year 2016 and 2017 respectively while Y1 had 12 and 11 species in the years 2016 and 2017 respectively having lowest diversity and Y3 had 13 species in 2016 and 12 species in 2017. Pielou's evenness showed highest value of 0.83 in Y1 in 2016 while the lowest value was 0.76 found in the year 2016 in Y3.A one way ANOVA showed significant variation between different ages of jhum lands with species richness ($r=.007$; $p<0.05$) and while no significant variation was found between different ages of jhum lands and abundance of spores ($r=.868$; $p<0.5$) in maize. A negative correlation was found between soil moisture and abundance of spores (-0.218) in Y1 and species richness in Y2 (-0.579) and Y3 (-0.013).No significant correlation was found on organic C, however a negative correlation was found with number of species in Y1 (-0.159), Y2 (-0.080) and Y3 (-0.096) while number of spores had negative correlation only in Y2 (-0.019). A significant negative correlation was found between N and number of spores in Y3 (-626*) and between species richness and P in Y1 (-0.796*).

For seasonal diversity in Banana, species richness and population of spores was found to be highest during monsoon season, followed by pre-monsoon and lowest during post monsoon season. The most abundant species were found to be *Funneliformis mosseae*, *Rhizophagus intradices, Glomus fasciculatum*, *Glomus multicaule, G. Fuegianum* and *G. microaggregatum*. These species are known to be one of the most beneficial AMF species around the world that provide and support their host plants even in adverse soil condition. The total number of spores recover from soil was 6121. Among the three study sites, Y2 had the highest diversity with Margalef's diversity index of 25.83 in the year 2016-17. Simpson dominance index showed highest during monsoon season in Y1(0.92) in both 2015-16 and 2016-17 while lowest during post monsoon season in the year 2016-17 in Y3 (0.86). Shannon

diversity index showed highest during monsoon season in Y2 (2.59) in the year 2016-17. Species richness and population of spores was found to be highest during monsoon season, followed by pre-monsoon and lowest during post monsoon season. Seasonal influence in species richness was found in this study. A negative correlation was found between soil moisture and abundance of spores (-0.218) in Y1 and species richness in Y2 (-0.579) and Y3 (-0.013). Temperature showed a positive correlation with species richness in Y1 (0.205) and Y2 (0.257) and abundance of spores in Y2 (0.099) while a negative correlation was found both with species richness and abundance of spores in Y3. N had a significant negative correlation with number of spores in Y1 (-0.770*) in Y1 and species richness (-0.875*) in Y3. While a positive correlation was found only with species richness in Y2. P also had a significant correlation with spore population (-0.821*) in Y1 while species richness showed positive correlation in all the study sites. A one way ANOVA conducted between the abundance of spores and different ages of jhum lands do not show any significant variation ($r=.143$; $p>0.05$) while different seasons showed a significant variation ($r=.000$; $p< 0.05$). However, a one way ANOVA done between species richness and different years of jhum land shows significant variation ($r=.013$; $p<0.05$) and also between different seasons with species richness show significant variation ($r=0.000$; $p<0.05$). It was believed that there was a limitation in AMF sporulation to soil temperature that caused to decrease the spore population during post monsoon. Seasonal studies of AM fungi help to predict the crucial conditions for their development. The uneven distribution of AM species could be attributed to spatial distribution, host specification, loss of species due to fire of dried slash when a field is prepared for cultivation, tillage, disturbances etc.

For Physico-chemical properties of soil, the sample soil was taken from each study sites every month from 2016 to 2017. Three replicates were formed in every soil analysis. 9 different soil parameters were taken from each site to study the effect of different ages of jhum lands which inturn affect AMF development. There is a clear observation in this study that different ages of jhum lands affect the soil conditions. In the meantime, several anthropogenic activities and intermittent farming in the jhum lands also found to affect the soil nutrients. Such disturbances

could decrease the nutrient content of soil to a larger extent. An intermittent farming in Y1 also found to reduce the soil nutrients even though the soil was already in a bad condition due to jhum cultivation. Several authors reported that the jhum fallows of between 1- 4 years had the most crucial stages of soil nutrition (Devi and Choudhury, 2013; Filho *et al.,* 2013). Such disturbances not only reduce soil organic matter but also reduce soil micro-organisms, increase bulk density etc.

In conclusion, results showed that AMF abundance, species richness and colonization vary among different ages of jhum lands greatly. Edaphic factors as well as seasonal changes have great influence in the formation and development of AMF. There is no significant evident to say the most influencing soil characteristics from this study but soil moisture content, soil temperature, P and N are found to influence the AMF colonization, diversity and population of spores to a great extent.It can be said that rainfall is also an important factor that the soil quality largely depends because from the results rainy season was best for higher root colonization, diversity and spore population while it lower during post monsoon season when there is water stress and low soil temperature.

This work highlighted the AMF association, species diversity and its relation to their host plants and soil characteristics. It provides the first baseline data on AMF association and diversity and the effect of different ages of jhum lands in Mizoram, India, which is expected to be important for further references. However, further studies like molecular level studies for taxonomy and ecological study in order to consider the occurrence of AM fungi in different ages of jhum lands and forests to provide accurate picture of AM fungal development and functioning in that given ecosystem is recommended.

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Appendix I: A one way ANOVA conducted to compare the effect of different ages of jhum on AMF colonization in Cowpea.

ANOVA

Colony

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3392.167	5	678.433	10.745	.000
Within Groups	3030.667	48	63.139		
Total	6422.833	53			

Multiple Comparisons in the year 2016

Dependent Variable: colonization

Tukey HSD

(I) VAR00002	(J) VAR00002	Std. Error	Sig.
1=Y1	2=Y2	3.14379	.855
	3=Y3	3.14379	.000
2=Y2	1=Y1	3.14379	.885
	3=Y3	3.14379	.009
3=Y3	1=Y1	3.14379	.000
	2=Y2	3.14379	.009

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons in the year 2017

Dependent Variable: colonization

Tukey HSD

(I) VAR00002	(J) VAR00002	Std. Error	Sig.
1=Y1	2=Y2	3.14379	.986
	3=Y3	3.14379	.000
2=Y2	1=Y1	3.14379	.986
	3=Y3	3.14379	.001
3=Y3	1=Y1	3.14379	.000
	2=Y2	3.14379	.001

*. The mean difference is significant at the 0.05 level.

Appendix II: A one way ANOVA conducted to compare the effect of different ages of jhum on AMF colonization in Maize.

ANOVA

colony

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6367.837	2	3183.919	5.586	.000
Within Groups	6399.482	69	92.746		
Total	12767.319	71			

Multiple Comparisons in the year 2016

Dependent Variable: colony

Tukey HSD

(I) years	(J) years	Std. Error	Sig.
1=Y1	2=Y2	1.31521	.982
	3=Y3	1.31521	.001
2=Y2	1=Y1	1.31521	.982
	3=Y3	1.31521	.017
3=Y3	1=Y1	1.31521	.001
	2=Y2	1.31521	.017

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons in the year 2017

Dependent Variable: colony

Tukey HSD

(I) years	(J) years	Std. Error	Sig.
1=Y1	2=Y2	1.31521	.732
	3=Y3	1.31521	.007
2=Y2	1=Y1	1.31521	.732
	3=Y3	1.31521	.000
3=Y3	1=Y1	1.31521	.007
	2=Y2	1.31521	.000

*. The mean difference is significant at the 0.05 level.

AppendixIII(a-c): A one way ANOVA conducted to compare the effect of different seasons to different ages of jhum on AMF colonization in Banana.

Appendix III(a): A one way ANOVA conducted during Pre-monsoon season

ANOVA

Premonsoon

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2034.093	5	406.819	7.217	.000
Within Groups	2705.556	48	56.366		
Total	4739.648	53			

Multiple Comparisons in the year 2015-2016

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	3.53917	.031
	3=Post monsoon	3.53917	.047
2=Monsoon	1=Pre monsoon	3.53917	.000
	3=Post monsoon	3.53917	.030
3=Post monsoon	1=Pre monsoon	3.53917	.035
	2=Monsoon	3.53917	.000

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons in the year 2016-2017

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	3.53917	1.000
	3=Post monsoon	3.53917	.001
2=Monsoon	1=Pre monsoon	3.53917	1.000
	3=Post monsoon	3.53917	.003
3=Post monsoon	1=Pre monsoon	3.53917	.001
	2=Monsoon	3.53917	.003

*. The mean difference is significant at the 0.05 level.

Appendix III(b): A one way ANOVA conducted during Monsoon season

ANOVA

Monsoon

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8581.903	5	1716.381	16.214	.000
Within Groups	6986.750	66	105.860		
Total	15568.653	71			

Multiple Comparisons in the year 2015-2016

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	4.20039	.998
	3=Post monsoon	4.20039	.001
2=Monsoon	1=Pre monsoon	4.20039	.998
	3=Post monsoon	4.20039	.000
3=Post monsoon	1=Pre monsoon	4.20039	.001
	2=Monsoon	4.20039	.000

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons in the year 2016-2017

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	4.20039	1.000
	3=Post monsoon	4.20039	.000
2=Monsoon	1=Pre monsoon	4.20039	1.000
	3=Post monsoon	4.20039	.000
3=Post monsoon	1=Pre monsoon	4.20039	.000
	2=Monsoon	4.20039	.000

*. The mean difference is significant at the 0.05 level.

Appendix III(c): A one way ANOVA conducted during Post-monsoon season

ANOVA

Postmonsoon

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1703.600	5	340.720	2.557	.033
Within Groups	11194.000	84	133.262		
Total	12897.600	89			

Multiple Comparisons in the year 2015-2016

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	4.21524	.855
	3=Post monsoon	4.21524	.000
2=Monsoon	1=Pre monsoon	4.21524	.855
	3=Post monsoon	4.21524	.059
3=Post monsoon	1=Pre monsoon	4.21524	.000
	2=Monsoon	4.21524	.059

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons in the year 2016-2017

Dependent Variable: colony

Tukey HSD

(I) season	(J) season	Std. Error	Sig.
1=Pre monsoon	2=Monsoon	4.21524	.986
	3=Post monsoon	4.21524	.001
2=Monsoon	1=Pre monsoon	4.21524	.986
	3=Post monsoon	4.21524	.010
3=Post monsoon	1=Pre monsoon	4.21524	.001
	2=Monsoon	4.21524	.010

*. The mean difference is significant at the 0.05 level.

Appendix IV: A one way ANOVA conducted to compare the effect of different ages of jhum on species richness and number of spores in Cowpea.

		Sum of Squares	df	Mean Square	F	Sig.
species	Between Groups	16.778	2	8.389	5.511	.016
	Within Groups	22.833	15	1.522		
	Total	39.611	17			
spores	Between Groups	3086.778	2	1543.389	1.051	.374
	Within Groups	22031.667	15	1468.778		
	Total	25118.444	17			

Appendix V: A one way ANOVA conducted to compare the effect of different ages of jhum on species richness and number of spores in Maize.

		Sum of Squares	df	Mean Square	F	Sig.
species	Between Groups	19.000	2	9.500	6.435	.007
	Within Groups	31.000	21	1.476		
	Total	50.000	23			
spores	Between Groups	2146.083	2	1073.042	1.024	.376
	Within Groups	22001.250	21	1047.679		
	Total	24147.333	23			

Appendix VI: A one way ANOVA conducted to compare the effect of different ages of jhum on species richness and number of spores in Banana.

ANOVA with different study sites						
		Sum of Squares	df	Mean Square	F	Sig.
species	Between Groups	70.194	2	35.097	4.595	.013
	Within Groups	527.083	69	7.639		
	Total	597.278	71			
spores	Between Groups	3288.528	2	1644.264	1.999	.143
	Within Groups	56742.083	69	822.349		
	Total	60030.611	71			

ANOVA with different seasons						
		Sum of Squares	df	Mean Square	F	Sig.
species	Between Groups	142.153	2	71.076	10.776	.000
	Within Groups	455.125	69	6.596		
	Total	597.278	71			
spores	Between Groups	26691.278	2	13345.639	27.621	.000
	Within Groups	33339.333	69	483.179		
	Total	60030.611	71			

Appendix VII (a-c) : Monthly occurrence of AMF spores from the three different study sites in Cowpea.

Appendix VII a: Occurrence of AMF spores during different month of study from Y1 in Cowpea (+ presence; - absence)

Name of species	May-16	Jun-16	Jul-16	May-17	Jun-17	Jul-17
Acaulospora tuberculata	+	-	+	-	+	+
Acaulospora scrobiculata	+	-	-	+	+	-
Funneliformis mosseae	+	+	-	+	+	+
Funneliformis badium	-	-	-	-	-	-
Gigaspora margarita	-	-	+	-	+	-
Glomus constrictum	-	-	-	+	+	-
Glomus fasciculatum	+	-	+	+	+	+
Glomus ambisporum	+	+	+	-	+	+
Glomus microcarpum	-	+	+	+	-	+
Glomus versiforme	-	-	-	-	-	-
Glomus glomeratum	+	+	+	+	-	+
Glomus aureum	-	-	-	-	-	-
Glomus botryoides	-	+	+	-	+	+
Glomus clavisporum	-	+	-	-	+	-
Rhizophagus intradices	+	-	+	+	+	-

Appendix VII b: Occurrence of AMF spores in Cowpea during different month of study from Y2

Name of species	May-16	Jun-16	Jul-16	May-17	Jun-17	Jul-17
Acaulospora tuberculata	-	+	+	-	-	+
Acaulospora scrobiculata	-	-	-	-	-	-
Funneliformis mosseae	+	+	+	+	-	+
Funneliformis badium	+	-	-	+	+	-
Gigaspora margarita	-	-	-	-	-	-
Glomus constrictum	-	+	+	+	-	-
Glomus fasciculatum	+	-	+	+	+	+
Glomus ambisporum	+	+	-	+	-	+

Glomus microcarpum	-	+	+	+	-	+
Glomus versiforme	-	+	+	+	+	+
Glomus glomeratum	-	+	+	+	-	+
Glomus aureum	+	-	-	+	-	-
Glomus botryoides	+	+	-	-	+	+
Glomus clavisporum	-	-	-	-	+	-
Rhizophagus intradices	+	+	-	-	+	+

Appendix VII c: Occurrence of AMF spores during different month of study from Y3 in Cowpea.

Name of species	May-16	Jun-16	Jul-16	May-17	Jun-17	Jul-17
Acaulospora tuberculata	+	-	+	-	+	-
Acaulospora scrobiculata	-	+	+	+	-	+
Funneliformis mosseae	+	+	+	+	+	+
Funneliformis badium	-	+	-	+	+	-
Gigaspora margarita	+	-	+	-	+	+
Glomus constrictum	-	+	+	+	-	+
Glomus fasciculatum	+	+	+	+	+	+
Glomus ambisporum	+	+	-	-	-	-
Glomus microcarpum	-	-	-	-	-	-
Glomus versiforme	-	-	-	-	-	-
Glomus glomeratum	+	-	+	+	-	+
Glomus aureum	-	-	-	-	-	-
Glomus botryoides	+	-	+	-	+	+
Glomus clavisporum	+	-	-	-	+	-
Rhizophagus intradices	+	+	+	+	+	-

Appendix VIII (a-c) : Monthly occurrence of AMF spores from the three different study sites in Maize.

Appendix VIII a: Occurrence of AMF spores during different month of study from Y1 in Maize

Name of species	May-16	Jun-16	Jul-16	Aug-16	May-17	Jun-17	Jul-17	Aug-17
Acaulospora laevis	+	-	+	+	-	+	+	+
Acaulospora tuberculata	-	-	-	-	+	-	+	-
Acaulospora scrobiculata	-	+	+	+	-	-	-	-
Funneliformis mosseae	+	+	+	-	+	+	+	+
Gigaspora margarita	-	-	-	-	-	-	-	-
Glomusgeo sporum	+	-	+	-	+	+	+	-
Glomus fasciculatum	+	+	+	+	-	+	+	+
Glomus verruculosum	-	-	-	-	-	-	-	-
Glomus microaggregatum	-	+	-	+	+	-	-	-
Glomus diserticola	-	-	+	-	-	-	-	-
Glomus clarum	-	+	-	+	+	+	-	+
Glomus fuegianum	+	-	-	-	-	+	+	-
Glomus botryoides	+	-	+	+	+	+	+	+
Glomus constrictum	+	+	-	-	+	+	-	+
Rhizophagus intradices	+	+	-	-	+	+	-	+

Appendix VIII b: Occurrence of AMF spores of Maize during different month of study from Y2

Name of species	May-16	Jun-16	Jul-16	Aug-16	May-17	Jun-17	Jul-17	Aug-17
Acaulospora laevis	+	-	+	+	+	-	-	-
Acaulospora tuberculata	+	-	+	-	-	+	-	+
Acaulospora scrobiculata	-	+	-	+	-	+	-	+
Funneliformis mosseae	-	+	+	-	+	+	+	-
Gigaspora margarita	-	-	-	+	-	-	+	-
Glomus geosporum	+	-	+	+	-	+	+	-
Glomus fasciculatum	+	+	+	-	+	+-	+	+

Glomus verruculosum	-	-	-	-	-	+	-	+
Glomus microaggregatum	+	-	+	-	+	-	-	-
Glomus diserticola	-	+	-	+	-	+	-	-
Glomus clarum	+	+	+	+	-	+	+	+
Glomus fuegianum	+	-	+	-	+	-	+	-
Glomus botryoides	+	-	+	+	+	+	+	+
Glomus constrictum	+	+	-	+	+	+	-	+
Rhizophagus intradices	+	+-	-	+	+	+	-	+

Appendix VIII c: Occurrence of AMF spores during different month of study from Y3

Name of species	May-16	Jun-16	Jul-16	Aug-16	May-17	Jun-17	Jul-17	Aug-17
Acaulospora laevis	+	-	+	+	-	-	+	+
Acaulospora tuberculata	-	-	-	-	+	+	-	+
Acaulospora scrobiculata	+	+	+	-	-	-	+	+
Funneliformis mosseae	+	+	+	-	+	+	-	+
Gigaspora margarita	-	-	-	-	-	-	-	-
Glomus geosporum	-	+	+	-	-	+	+	+
Glomus fasciculatum	+	+	+	+	+	+	-	+
Glomus verruculosum	+	-	+	-	+	+	-	-
Glomus microaggregatum	-	-	-	-	-	-	-	-
Glomus diserticola	-	-	-	+	+	-	-	-
Glomus clarum	-	+	+	+	+	+	+	+
Glomus fuegianum	+	-	+	-	-	+	+	-
Glomus botryoides	-	+	+	-	+	-	+	+
Glomusconstrictum	+	-	+	+	-	-	-	-
Rhizophagusintradices	+	+	-	+	+	-	+	-

+=present - =absent

Appendix IX(a-c): Monthly occurrence of AMF spores from Y1 in Banana

Appendix IXa: Occurrence of AMF species during Pre monsoon season in Y1.

Name of species	Mar-16	Apr-16	May-16	Mar-17	Apr-17	May-17
Acaulospora tuberculata	-	+	+	-	+	-
A. laevis	-	-	-	-	-	-
A. scrobiculata	+	-	-	+	+	+
A. foveata	-	-	+	+	-	+
Entropospora schenckii	-	+	+	-	+	+
Funneliformis coronatum	-	+	-	+	+	-
F. badium	-	+	-	+	-	+
F.mosseae	-	+	+	-	+	+
Gigaspora albida	-	-	-	-	-	-
Glomus multicaule	-	+	+	-	+	-
G. aureum	+	-	-	+	-	+
G. geosporum	-	+	-	-	-	-
G. botryoides	-	+	+	+	-	+
G. ambisporum	-	-	-	+	-	+
G. macrocarpum	+	-	-	-	-	-
G. microcarpum	+	-	+	+	+	+
G. fasiculatum	-	+	+	-	+	+
G. fuegianum	+	-	+	-	+	-
G. microaggregatum	-	-	-	-	-	-
G. clavisporum	+	-	-	-	-	-
G. versiforme	-	-	+	-	-	+
G. clarum	+	-	+	+	-	+
G. diserticola	-	-	+	-	+	-
G. constrictum	+	+	-	-	-	-
G. glomeratum	-	-	-	-	+	+
G. taiwanese	-	-	-	-	-	-
G. maculosum	-	+	-	+	+	-
G. rubiforme	+	-	-	+	-	+
Rhizophagus intradices	+	-	+	+	-	-

Appendix IXb:Occurrence of AMF species during Monsoon season in Y1.

Name of species	Jun-16	Jul-16	Aug-16	Sep-16	Jun-17	Jul-17	Aug-17	Sep-17
Acaulospora tuberculata	-	-	+	-	+	+	-	+
A. laevis	-	-	-	-	-	-	-	-
A. scrobiculata	+	-	+	+	-	+	-	-
A. foveata	+	-	-	-	+	+	-	+
Entropospora schenckii	-	+	+	-	+	+	-	+
Funneliformis coronatum	+	-	-	-	-	-	+	-
F. badium	-	-	-	-	-	-	-	+
F.mosseae	-	+	-	+	-	+	+	+
Gigaspora albida	-	+	-	+	-	+	+	-
Glomus multicaule	-	-	+	-	+	-	-	+
G. aureum	-	+	-	+	+	-	+	-
G. geosporum	+	-	-	-	-	-	-	-
G. botryoides	-	-	+	+	+	+	+	-
G. ambisporum	-	-	-	-	-	-	-	-
G. macrocarpum	+	-	+	-	-	+	-	+
G. microcarpum	-	+	-	+	+	-	-	-
G. fasiculatum	+	-	+	-	+	-	+	+
G. fuegianum	-	-	+	-	-	+	-	+
G. microaggregatum	-	-	+	-	+	+	-	+
G. clavisporum	-	-	-	-	-	-	-	-
G. versiforme	-	-	-	-	+	+	-	+
G. clarum	-	+	+	+	+	-	+	+
G. diserticola	-	-	+	+	-	-	+	-
G. constrictum	+	-	+	-	-	+	+	-
G. glomeratum	-	+	-	-	+	-	+	+
G. taiwanese	-	-	-	-	-	-	-	-
G. maculosum	+	-	+	-	-	-	-	-
G. rubiforme	-	+	-	+	+	-	+	+
Rhizophagus intradices	+	-	-	-	+	-	+	+

Appendix IXc:Occurrence of AMF species during Post monsoon season in Y1

Name of species	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Oct-16	Nov-16	Dec-17	Jan-17	Feb -17
Acaulospora tuberculata	+	-	+	-	+	-	-	+	-	-
A. laevis	-	-	-	-	-	-	-	-	-	+
A. scrobiculata	-	+	-	-	+	+	-	-	-	-
A. foveata	-	-	-	-	-	-	-	-	-	-
Entrospora schenckii	-	-	-	-	-	-	-	-	-	-
Funneliformis coronatum	-	+	+	+	-	-	-	+	-	-
F. badium	-	-	+	-	-	-	-	-	-	-
F.mosseae	+	-	-	+	+	-	+	-	+	-
Gigaspora albida	-	-	+	+	-	-	-	+	+	-
Glomus multicaule	+	+	-	+	-	-	-	+	-	-
G. aureum	+	-	+	-	-	-	-	-	+	-
G. geosporum	-	+	-	-	-	-	+	-	-	+
G. botryoides	-	-	-	-	-	-	-	-	-	-
G. ambisporum	-	-	-	-	-	-	-	-	-	-
G. macrocarpum	+	-	+	+	+	+	+	-	+	+
G. microcarpum	+	-	+	+	-	-	+	-	-	+
G. fasiculatum	+	-	-	-	+	+	-	-	-	-
G. fuegianum	-	+	-	-	-	-	+	+	-	-
G. microaggregatum	+	-	+	-	+	+	-	-	-	-
G. clavisporum	+	+	-	-	-	-	-	-	-	-
G. versiforme	-	-	-	-	+	-	-	-	-	+
G. clarum	+	+	+	+	-	-	-	-	+	-
G. diserticola	-	-	-	+	-	-	-	-	-	-
G. constrictum	-	+	+	-	-	-	-	+	+	+
G. glomeratum	-	-	+	-	+	-	-	-	-	-

G. taiwanese	-	-	-	-	-	-	-	-	-	-
G. maculosum	-	-	-	-	-	-	-	-	-	-
G. rubiforme	-	-	-	-	-	-	-	+	+	-
Rhizophagus intradices	-	-	+	-	-	-	-	-	-	+

Appendix X (a-c): Monthly occurrence of AMF spores from Y2 in Banana

Appendix Xa: Occurrence of AMF species during Pre monsoon season in Y2.

Name of species	Mar-16	Apr-16	May-16	Mar-17	Apr-17	May-17
Acaulospora tuberculata	-	-	+	-	+	-
A. laevis	-	+	-	+	-	-
A. scrobiculata	+	-	-	-	+	-
A. foveata	-	+	+	-	+	-
Entropospora schenckii	-	-	+	-	-	-
Funneliformis coronatum	+	-	-	+	+	-
F. badium	-	+	-	+	-	+
F.mosseae	+	-	+	+	+	+
Gigaspora albida	-	+	-	+	-	+
Glomus multicaule	+	-	+	+	-	+
G. aureum	-	+	-	-	+	-
G. geosporum	-	-	-	-	+	+
G. botryoides	+	-	+	-	+	-
G. ambisporum	-	-	-	-	+	-
G. macrocarpum	+	-	-	-	-	+
G. microcarpum	-	+	-	-	+	+
G. fasiculatum	-	-	+	-	-	+
G. fuegianum	-	+	-	+	-	-
G. microaggregatum	+	-	+	-	+	-
G. clavisporum	-	-	-	-	-	-
G. versiforme	+	+	-	+	-	-
G. clarum	-	-	-	+	+	+
G. diserticola	-	-	-	-	-	-

G. constrictum	+	-	-	+	-	-
G. glomeratum	-	+	-	-	+	+
G. taiwanese	-	-	-	-	-	-
G. maculosum	-	-	+	-	+	-
G. rubiforme	-	+	-	-	-	-
Rhizophagus intradices	+	+	-	-	+	-

Appendix Xb: Occurrence of AMF species during Monsoon season in Y2.

Name of species	Jun-16	Jul-16	Aug-16	Sep-16	Jun-17	Jul-17	Aug-17	Sep-17
Acaulospora tuberculata	-	+	-	+	-	+	+	-
A. laevis	-	-	+	+	-	+	-	-
A. scrobiculata	+	-	-	-	-	+	-	+
A. foveata	-	+	-	+	-	-	+	+
Entropospora schenckii	-	+	+	-	-	+	-	-
Funneliformis coronatum	+	+	-	-	-	+	-	-
F. badium	-	+	-	+	-	-	-	-
F.mosseae	-	-	+	+	+	-	-	+
Gigaspora albida	-	+	-	+	-	-	-	-
Glomus multicaule	-	+	-	+	-	-	+	-
G. aureum	-	-	-	-	-	-	+	-
G. geosporum	-	-	-	+	-	+	-	-
G. botryoides	+	-	-	+	-	+	-	-
G. ambisporum	-	+	-	-	-	-	+	-
G. macrocarpum	-	-	-	-	-	-	+	-
G. microcarpum	-	-	-	-	-	+	-	+
G. fasiculatum	-	-	-	-	+	-	-	+
G. fuegianum	+	-	+	+	-	+	-	-
G. microaggregatum	-	+	+	-	+	+	+	-
G. clavisporum	+	-		-	+	-	+	-
G. versiforme	-	-	+	-	+	+	-	-
G. clarum	+	-	+	-	-	-	+	+

G. diserticola	-	-	-	-	-	-	-	-
G. constrictum	-	-	-	-	+	+	-	-
G. glomeratum	-	-	+	-	-	-	+	-
G. taiwanese	-	+	-	-	-	-	-	+
G. maculosum	-	-	+	-	-	+	-	-
G. rubiforme	-	-	-	+	-	+	-	+
Rhizophagus intradices	-	-	+	-	+	+	+	+

Appendix Xc: Occurrence of AMF species during Post-monsoon season in Y2.

Name of species	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17
Acaulospora tuberculata	-	-	-	-	-	-	-	-	-	-
A. laevis	-	-	-	+	+	-	-	+	-	+
A. scrobiculata	+	+	-	-	-	+	+	-	+	-
A. foveata	-	-	-	+	-	-	-	+	-	+
Entrospora schenckii	+	+	-	-	-	-	-	-	+	-
Funneliformis coronatum	-	+	-	-	-	+	-	-	-	-
F. badium	-	-	+	-	-	+	-	+	-	-
F.mosseae	-	+	-	+	+	+	+	-	-	+
Gigaspora albida	-	-	-	-	-	-	-	-	-	-
Glomus multicaule	+	-	+	-	+	-	-	+	+	-
G. aureum	-	-	-	-	-	-	-	-	-	-
G. geosporum	+	-	+	+	-	-	+	-	-	-
G. botryoides	-	-	-	-	+	-	-	+	+	-
G. ambisporum	-	-	-	-	-	-	-	-	-	-
G. macrocarpum	-	-	-	-	-	-	-	-	-	+
G. microcarpum	-	+	+	-	-	+	+	+	+	-
G. fasiculatum	-	-	+	-	-	-	+	+	+	-

G. fuegianum	+	-	-	-	+	-	-	+	-	-
G. microaggregatum	-	+	-	+	-	-	-	-	-	+
G. clavisporum	-	-	-	-	-	-	-	-	-	-
G. versiforme	-	-	-	-	-	-	-	-	-	-
G. clarum	-	+	+	-	+	-	-	-	-	-
G. diserticola	-	-	-	-	-	-	-	-	-	-
G. constrictum	+	-	-	-	-	+	+	+	-	+
G. glomeratum	-	-	+	+	-	-	-	-	-	-
G. taiwanese	-	-	+	-	+	-	-	-	-	+
G. maculosum	-	-	-	-	-	+	-	+	+	-
G. rubiforme	+	+	-	+	-	-	+	+	-	+
Rhizophagus intradices	-	+	-	+	-	-	+	-	-	-

Appendix XI (a-c): Monthly occurrence of AMF spores from Y3 in Banana

Appendix XIa: Occurrence of AMF species during Pre monsoon season in Y3.

Name of species	Mar-16	Apr-16	May-16	Mar-17	Apr-17	May-17
Acaulospora tuberculata	+	-	-	+	+	-
A. laevis	-	-	-	-	-	-
A. scrobiculata	-	+	-	+	-	-
A. foveata	-	+	+	+	-	-
Entropospora schenckii	-	-	-	-	-	-
Funneliformis coronatum	-	-	-	-	-	-
F. badium	-	+	-	-	+	-
F.mosseae	-	+	+	+	-	+
Gigaspora albida	-	-	-	-	-	-
Glomus multicaule	+	+	-	+	+	-
G. aureum	-	+	-	-	+	+
G. geosporum	-	-	-	-	-	-
G. botryoides	-	+	-	+	+	+
G. ambisporum	-	-	-	-	-	-

G. macrocarpum	+	+	+	-	-	-
G. microcarpum	-	-	-	-	+	+
G. fasiculatum	+	-	+	+	+	+
G. fuegianum	-	-	-	+	-	-
G. microaggregatum	-	+	-	-	-	+
G. clavisporum	+	-	-	-	-	-
G. versiforme	-	-	-	-	-	-
G. clarum	-	+	-	+	+	+
G. diserticola	-	-	-	-	-	-
G. constrictum	-	-	-	-	-	-
G. glomeratum	-	+	-	+	+	-
G. taiwanese	-	-	+	-	+	-
G. maculosum	-	+	-	-	-	-
G. rubiforme	-	-	+	+	-	+
Rhizophagus intradices	+	+	-	+	+	+

Appendix XI b: Occurrence of AMF species during Monsoon season in Y3.

Name of species	Jun-16	Jul-16	Aug-16	Sep-16	Jun-17	Jul-17	Aug-17	Sep-17
Acaulospora tuberculata	-	-	-	-	-	-	+	-
A. laevis	-	+	+	-	-	+	-	-
A. scrobiculata	+	-	-	+	+	+	-	-
A. foveata	+	-	+	-	+	-	-	-
Entropospora schenckii	-	+	-	-	-	-	-	-
Funneliformis coronatum	-	-	-	-	-	-	-	-
F. badium	-	-	+	-	-	-	-	+
F.mosseae	-	+	-	+	+	+	+	-
Gigaspora albida	-	-	-	-	-	-	-	-
Glomus multicaule	-	+	+	-	-	-	-	-
G. aureum	+	-	-	+	-	+	+	-
G. geosporum	-	-	-	-	-	-	-	-
G. botryoides	+	-	+	-	+	-	+	-

G. ambisporum	-	+	-	+	-	-	+	-
G. macrocarpum	-	+	+	-	-	-	-	+
G. microcarpum	-	-	-	-	+	+	+	-
G. fasiculatum	+	+	-	+	-	-	+	+
G. fuegianum	+	-	-	+	+	-	+	-
G. microaggregatum	-	-	+	-	-	+	-	+
G. clavisporum	-	-	-	-	-	-	-	-
G. versiforme	+	-	+	-	-	+	-	-
G. clarum	+	-	-	+	+	+	-	+
G. diserticola	+	-	-	+	-	+	-	-
G. constrictum	-	+	-	+	-	+	-	-
G. glomeratum	-	-	-	-	-	-	-	-
G. taiwanese	-	-	-	-	-	-	-	+
G. maculosum	+	-	+	+	-	+	+	-
G. rubiforme	-	-	-	-	-	-	+	+
Rhizophagus intradices	-	-	+	-	+	-	+	-

Appendix XI c: Occurrence of AMF species during Post monsoon season in Y3.

Name of species	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17
Acaulospora tuberculata	-	-	-	-	-	-	+	-	-	-
A. laevis	+	-	+	-	+	+	-	+	+	+
A. scrobiculata	-	-	-	-	-	-	-	-	-	+
A. foveata	-	-	-	-	-	-	-	-	-	+
Entrospora schenckii	-	-	-	-	-	-	-	-	-	-
Funneliformis coronatum	-	-	-	-	-	-	-	-	-	-
F. badium	+	-	-	-	+	+	-	-	-	-
F.mosseae	-	+	-	+	+	+	-	+	-	-
Gigaspora albida	-	-	-	-	-	-	-	-	-	-

Glomus multicaule	+	-	-	-	+	-	-	-	-	-
G. aureum	-	+	+	-	-	-	+	-	-	-
G. geosporum	+	-	+	+	-	-	-	-	-	-
G. botryoides	+	-	-	-	+	-	+	+	-	-
G. ambisporum	-	-	-	-	-	-	-	-	-	+
G. macrocarpum	-	-	-	-	-	-	-	-	-	-
G. microcarpum	-	-	-	-	+	+	-	+	-	-
G. fasiculatum	-	+	-	+	-	-	-	-	+	+
G. fuegianum	+	-	-	+	-	-	+	-	-	-
G. microaggregatum	-	-	+	+	-	+	-	-	+	+
G. clavisporum	-	-	-	-	-	-	-	-	-	-
G. versiforme	-	-	-	-	-	+	+	-	+	-
G. clarum	+	+	-	+	-	+	-	+	-	-
G. diserticola	-	-	-	-	-	-	-	-	-	-
G. constrictum	+	-	+	-	+	+	-	+	-	+
G. glomeratum	-	+	+	+	+	-	+	-	+	+
G. taiwanese	-	-	-	-	-	-	-	-	-	-
G. maculosum	-	-	-	-	-	-	-	-	-	-
G. rubiforme	-	-	-	-	-	-	-	-	-	-
Rhizophagus intradices	+	+	-	+	-	+	-	+	+	+

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1. Lalnunthari, John Zothanzama and Lalfakzuala, R. (2016). Colonization of Arbuscular Mycorrhizal fungi (AMF) in Cowpea (VIGNA SPS) from Three Different Jhum Lands in Mizoram. *IJSRST* 4(5): 724-726
2. Lalnunthari and John Zothanzama, (2018). Colonization of Arbuscular Mycorrhizal Fungi (AMF) in Maize from Three Different jhum lands in Mizoram, India. *Science and Technology Journal* 6(2) : 37-43
3. Lalnunthari, John Zothanzama and Saizamrengi, (2019). Arbuscular mycorrhizal fungi in Melocanna baccifera from disturbed and undisturbed sites in Mizoram, India. *Science Vision* 19(2): 24-29

LIST OF PAPER PUBLISHED IN SYMPOSIUM/SEMINAR /CONFERENCES

1. Lalnunthari, John Zothanzama and R. Lalfakzuala (2016). Colonization of Arbuscular Mycorrhizal Fungi (AMF) from jhumlands of Mizoram. *Science and Technology for shaping the future of Mizoram*. Proceedings of the Mizoram Science Congress, 2016, Allied Publishers Private Limited, New Delhi, pp 175-178
2. Lalnunthari, John Zothanzama and R. Lalfakzuala (2018). Arbuscular Mycorrhizal Fungi (AMF) on Some Selected Plants in Mizoram, Northeast India. In: *Climate Change; Impact, Adaptation and Response in the Eastern Himalayas*. Proceedings of the Regional Seminar on Indian Himalayas Climate Adaptation Programme. John Zothazama, Benjamin L. Saitluanga, Lalnuntluanga, S.T. Lalzarzovi and R. Zonunsanga (Edition), (2018). Excel India Publishers, pp 140-143

LIST OF PAPER PRESENTED IN SYMPOSIUM/SEMINAR /CONFERENCES

1. "*Colonization of Arbuscular Mycorrhizal Fungi (AMF) in Banana from Jhumlands in Mizoram, India*" in Two-Day Workshop on Current Trents of Biodiversity Research in Mizoram held on 20th and 21st March, 2015 sponsored by CSIR, New Delhi (GoI), organised by Department of Environmental Science, Mizoram University and Department of Zoology, Pachunga University College.
2. "*Colonization of Arbuscular Mycorrhizal Fungi (AMF) from Jhumlands of Mizoram*" in Mizoram Science Congress held at Mizoram University during 13th – 14th October, 2016 sponsored by NEC, DST (SERB) & MISTIC.
3. "*Monthly variation in percent root colonization and spore number in banana from three different jhum lands in Mizoram*" in National Seminar on Biodiversity Conservation and Utilization of Natural Resources with references to Northeast India (BCUNRNEI) held on 30th – 31st March, 2017 at Mizoram University.

LIST OF SYMPOSIUM/SEMINAR /CONFERENCES/WORKSHOPS ATTENDED

1. *International Symposium on Integrated Land Use Management in Eastern Himalaya* held on 17th – 22nd at Mizoram University, Aizawl, Mizoram.
2. *Seminar on Oil and Natural Gas in Mizoram: Present Scenario and Prospects* held on 28 August 2013 at Pi Zaii Hall, Synod Conference Centre, Aizawl, Mizoram.
3. *National Seminar on Issues of Wildlife Conservation in India with Special References to Mizoram* held on 24th – 25th April, 2014 at Mizoram University, Aizawl, Mizoram.
4. *Two-Day Workshop on Current Trents of Biodiversity Research* in Mizoram held on 20th& 21st March, 2015, sponsored by CSIR, New Delhi (GoI), organised by Department of Environmental Science, Mizoram University and Department of Zoology, Pachunga University College.
5. *Workshop on Northeast India Biodiversity Portal* organised by Ashoka Trust For Research in Ecology and the Environment (ATREE) in collaboration with Mizo Academy of Science on May 7th 2016.
6. *Mizoram Science Congress* held at Mizoram University during 13th – 14th October, 2016.
7. *One Day Workshop on EIA* at Aijal Club, Aizawl on the 11th November, 2016.
8. *State Level Workshop & Round Table Discussion on "Combating Climate Change"* held at Aijal Club Conference Hall, Aizawl on 20th April, 2018, organised by the Mizoram Sustainable Development Foundation (MSDF), under the aegis of the Integrated Mountain Initiative (IMI) and the National Mission on Himalayan Studies (NMHS).
9. *Science and Technology for a Sustainable Future* catalysed and supported by the National Council of Science & Technology Communication, Department of Science and Technology, New Delhi on 30th April, 2018 at the Seminar Hall, PUC, Aizawl, Mizoram.

PARTICULARS OF THE CANDIDATE

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DEGREE : Doctor of Philosophy

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TITLE OF THE THESIS : **"**STUDY ON ARBUSCULAR MYCORRHIZAL FUNGI (AMF) COMMUNITIES FROM JHUM LANDS IN MIZORAM, INDIA".

DATE OF ADMISSION : 14th August, 2012.

APPROVAL OF RESEARCH PROPOSAL

1) DRC :22nd March, 2013
2) BOS : 5th April, 2013
3) SCHOOL BOARD : 13th May, 2013

MZU REGISTRATION :4557 of 2009-10

Ph.D. REGISTRATION NO.& DATE: MZU/Ph.D/528 of 13.05.2013

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Abstract

Mizoram, a state of India is located in the north-eastern part of the country. The climate of Mizoram is moderate ranging from 10ºC to 30ºC. Rainfall averages about 2500 mm annually. Agriculture is the dominant economic activity of Mizoram, engaging more than two thirds of the workforce. Cowpea, maize and banana are among the important crops produced in Mizoram. Shifting cultivation is one of the main forms of agriculture in Mizoram and other North Eastern Regions of India and is commonly known as *jhuming*. This system often involves clearing a piece of land by slashing and burning of woods followed by wood harvesting or farming. Once the land becomes unproductive, it is left to be reclaimed by regeneration of natural vegetation, or sometimes converted to different long-term cyclical farming practices (Mantel *et al*., 2006). An increase in the number of people farming in the 20th century forced a reduction in the traditional eight to ten year cycle of jhum regeneration, which inturn resulted in a decrease in the farm productivity.

A mycorrhiza is a symbiotic association between a fungus and the roots of a vascular plant. In this association, the fungus colonizes the host plants roots, either intracellular as in arbuscular mycorrhizal (AM) fungi or extracellularly as in ectomycorrhizal fungi. They are an important component of soil life and soil chemistry. AM fungi are known to improve the nutritional status, growth and development of plants, protect plants against root pathogens and also offer resistance to drought and salinity (Jeffries, 1987). They play a fundamental role in soil fertility and in the maintenance of stability and biodiversity within plant communities (Giovannetti and Avio, 2002). Though AMF has gained interest globally in the field of horticulture and agriculture due to their activity within the root system of their host plants and their ability to enhance water and mineral nutrition absorption and tolerance to different environmental stress factors (Smith and Read, 2008) there is a lack of report on the study AMF in Mizoram.

Keeping in view the inadequacy, the study on AM Fungal communities was conducted to assess the association, diversity and taxonomy of AM Fungi (AMF) in Cowpea, Maize and Banana from three different jhum fallows by taking up with the

following objectives: i) Taxonomical study of Arbuscular Mycorrhizal Fungi species. ii) To study association of Arbuscular Mycorrhizal Fungi with the selected plants. iii) To study the diversity of Mycorrhizal communities in the selected sites. iv) To analyze the physico-chemical characteristics of the soil in the selected sites.

The selected jhum fallows are of three different years i.e., 3 years, 6 years and 10 years. These fallows are situated at Muallungthu village in Aizawl District, Mizoram, India. It lies at Latitude 23°36'41"N and Longitude 92°43'10"E. The topography is moderately steep with an average slope angle range of 20-26º. Soil samples from the rhizophere region of cowpea and maize were collected during their growth period while for Banana, soil samples was collected in seasonal basis to study AMF diversity, spore population and soil characteristics. The fine roots were also collected from the selected plants to study AMF association with their host plants.

The findings of the study are summarized below:

Taxonomical study of AMF species through sporocarpic characters and features resulted in the identification of 31 species. Among the identified species, 20 belong to *Glomus* species, 4 species belongs to *Acaulospora*, 3 species belongs to *Funneliformis.* Only 2 species of *Gigaspora*, 1 species of *Entrophosphora* and 1 species of *Rhizophagus* were identified.

For association of AMF in cowpea, the highest colonization percentage was found in Y2 in the month of May 2016 i.e., 60% while the lowest 29% was found in Y3 in the month of July, 2016. By taking the average AM colonization percentage, Y2 had the highest percentage having 51.5% followed by Y1 with 51% and Y3 had the lowest with 41.5%. A one way ANOVA between different ages of jhum on AMF colonization in cowpea show a significant effect of jhum on AMF colonization at $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 3.357$, $p=0.000<0.05$. Post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2, $p= 0.855>0.05$, while a statistical difference was in Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.009< 0.05$ in the year 2016. There was also no statistical difference between Y1 & Y2, $p= .986>0.05$ however, there was a statistical difference between Y1 & Y3 $p=.000< 0.05$ and Y2 & Y3 $p=.001< 0.05$ in the year

2017. Pearson correlation showed a significant negative correlation between soil temperature (-0.836*), N (-0.751*) and P (-0.803*) in Y3 while Y1 and Y2 do not show any significant correlation with any of the soil parameters.

For association of AMF in maize, the AM colonization was found to be highest in Y1 51.75% and 54.25% and lowest in Y3 39% and 42% during 2016 and 2017 respectively. A statistical analysis between the three jhum lands with percentage colonization in the host plant shows a significant variation. A one way ANOVA between different ages of jhum on AMF colonization in maize show a significant effect of jhum on AMF colonization $p< 0.05$ level for the three treatment i.e. $F (5, 71) = 5.856$, $p = 0.000<0.05$. A post hoc comparisons using the Tukey's HSD indicated that there was no statistical difference between Y1 & Y2 ($p= 0.982>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.017< 0.05$) and Y1 & Y3 ($p=0.001< 0.05$) in the year 2016. There was no statistical difference between Y1 & Y2 ($p= 0.732>0.05$) while there was a statistical difference between Y2 & Y3 ($p=0.000< 0.05$) and Y1 & Y3 ($p=0.007< 0.05$) in 2017. A significant positive correlation was found between colonization and soil moisture content in Y1 (0.660*) and C in Y3 (0.605*). Pearson's correlation showed a negative correlation between AMF colonization against P in Y2 (-0.174) and Y3 (-0.404), while a positive correlation in Y1 (0.516) which indicates that the higher phosphorus content have negative influence and have effect with lower AMF colonization.

For AMF association in banana, the study was conducted in a seasonal basis. Colonization of AMF was found highest during monsoon season and lowest during post monsoon season. Y2 had the highest colonization percentage among the three study sites. Humid and warm climate appear to favour the colonization which resulted in the increase of colonization percentage during monsoon season while soil temperature can be as low as below 10°C during post monsoon season resulting in lower colonization. A seasonal influence on the colonization can be clearly seen through the results. A one way ANOVA conducted between AMF colonization and different ages of jhum lands during different seasons showed a significant variation $p< 0.05$ level for the three treatment i.e. $F (5, 53) = 7.217$, $p=0.000<0.05$ for pre-

monsoon, F (5, 71) = 16.214, p=0.000<0.05 for monsoon and F (5, 71) = 2.557, p=0.003<0.05 for post-monsoon season. Pearson's correlation between different soil parameter and AMF colonization in the different study sites showed a significant negative correlation was found between P and colonization in Y3 (-0.922*) while a positive significant correlation was observed in the soil moisture content (0.895*) in Y3 and C in Y1 (0.860*). AMF colonization also showed negative correlation with soil temperature (-0.496) in Y3, bulk density (-0.232) in Y1, porosity in all the study sites, pH in Y1 (-0.013) and Y3 (-0.091), C in Y3 (-0.314), N in Y3 (-0.620) and P and K in all the study sites.

In diversity of cowpea, *Funneliformis mosseae* (formerly *Glomus mosseae*) was the most abundant AMF species recovered contributing 24.5% of the whole AMF population while *Rhizophagus intradices (*formerly *Glomus intradices)* came in second with 19.6% and third was *Glomus fasciculatum* contributing 22.3% of the population. The total number of species identified from the rhizosphere was 15 belonging to 5 genera. 12 species were found to occur in Y1 and Y3 while 13 numbers of species was found in Y2. The Simpson dominance index showed a high dominance in Y3 as compared to Y1 and Y2. Pielou's evenness index E showed a lowest in Y1 in 2016 and highest in Y2 in the year 2017. Shannon Weaver index of diversity was found to be lowest in Y3 (2017) and highest in Y2 (2017). Increase in diversity was found from 2016 and 2017 except in Y3. A one way ANOVA showed no significant variation between different ages of jhum lands and number of spores (r=.374; p>.05) while a one way ANOVA conducted between the different ages of jhum lands and species richness showed a significant variation r=.016; p<0.05. A negative significant correlation (-0.922**) was found between species diversity and soil moisture content in Y2. A significant negative correlation was also found between N and number of spores (-0.863*) in Y3 while no significant negative correlation was found with P while it showed negative correlation with both species richness and spore population in all the sites except in Y3 where species richness show a positive correlation (0.083). K was found to have a significant negative correlation (-0.816*) with species richness in Y2. The number of spores was found to be highest in Y2 (515) and lowest in Y3 (475).

In maize, there are two dominant species in Y1 *Rhizophagus intradices* and *Funneliformis mosseae* which account for 53.9% of the total spores counted. *Glomus fasciculatum, G. fuegianum, G, microaggregatum, Rhizophagus intradices and Funneliformis mosseae* were the dominant species in Y2 contributing more than 85% of total AMF spores while *G. fasciculatum, G. fuegianum, R. intradices and F. Mosseae* were the dominant species in Y3 which contribute more than 60% of the total spores counted. A total of 15 species were recovered from maize belonging to five (5) genera. Y2 has got the highest diversity as analysed by Shannon diversity index containing 14 and 15 different species in the year 2016 and 2017 respectively while Y1 had 12 and 11 species in the years 2016 and 2017 respectively having lowest diversity and Y3 had 13 species in 2016 and 12 species in 2017. Pielou's evenness showed highest value of 0.83 in Y1 in 2016 while the lowest value was 0.76 found in the year 2016 in Y3. Margalef's species richness was highest in Y2 (14.81) in the year 2017. Simpson dominance index was found to be highest in Y2 (0.87) in the year 2016 and lowest in Y1 (0.81) in the year 2017. A one way ANOVA showed significant variation between different ages of jhum lands with species richness ($r=.007$; $p<0.05$) and while no significant variation was found between different ages of jhum lands and abundance of spores ($r=.868$; $p<0.5$). A negative correlation was found between soil moisture and abundance of spores (-0.218) in Y1 and species richness in Y2 (-0.579) and Y3 (-0.013). No significant correlation was found in C, whereas a negative correlation was found with number of species in Y1 (-0.159), Y2 (-0.080) and Y3 (-0.096) and the number of spores had negative correlation only in Y2 (-0.019). A significant negative correlation was found between Nand number of spores in Y3 (-626*) and between species richness and P in Y1 (-0.796*). Y2 had the most abundance spore while Y3 had the least AMF spore abundance among the three different studied jhum lands.

For seasonal diversity in banana, the most abundant species were found to be *Funneliformis mosseae*, *Rhizophagus intradices, Glomus fasciculatum*, *Glomus multicaule, G. Fuegianum* and *G. microaggregatum.* The total number of spores recover from soil was 6121. Among the three study sites, Y2 had the highest diversity with Margalef's diversity index of 25.83 in the year 2016-17. Simpson

dominance index showed highest during monsoon season in Y1(0.92) in both 2015-16 and 2016-17 while lowest during post monsoon season in the year 2016-17 in Y3 (0.86). Shannon diversity index showed highest during monsoon season in Y2 (2.59) in the year 2016-17. Species richness and population of spores was found to be highest during monsoon season, followed by pre-monsoon and lowest during post monsoon season. Seasonal influence on species richness was found in this study. A negative correlation was found between soil moisture and abundance of spores (-0.218) in Y1 and species richness in Y2 (-0.579) and Y3 (-0.013). Temperature showed a positive correlation with species richness in Y1 (0.205) and Y2 (0.257) and abundance of spores in Y2 (0.099) while a negative correlation was found both with species richness and abundance of spores in Y3. N had a significant negative correlation with number of spores in Y1 (-0.770*) in Y1 and species richness (-0.875*) in Y3. While a positive correlation was found only with species richness in Y2. P also had a significant correlation with spore population (-0.821*) in Y1 while species richness showed positive correlation in all the study sites. A one way ANOVA conducted between the abundance of spores and different ages of jhum lands do not show any significant variation ($r=.143$; $p>0.05$) while different seasons showed a significant variation ($r=.000$; $p< 0.05$). However, a one way ANOVA done between species richness and different years of jhum lands showed significant variation ($r=.013$; $p<0.05$) and also between different seasons with species richness showed significant variation ($r=0.000$; $p<0.05$).