AGRO-ECOLOGICAL STUDIES ON TWO SELECTED *MUSA* CULTIVARS PLANTED IN CULTIVATED AND ABANDONED JHUM LAND OF MOKOKCHUNG DISTRICT, NAGALAND

THESIS SUBMITTED

TO

NAGALAND UNIVERSITY

IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD

OF

DOCTOR OF PHILOSOPHY IN BOTANY

By

Mr. WATITEMJEN

Registration No: Ph. D./BOT/00158

Date: 18/08/2018

DEPARTMENT OF BOTANY

SCHOOL OF SCIENCES

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2023

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April 17th, 2023

DECLARATION

I, Mr. Watitemjen bearing Ph. D. Registration No: Ph. D./BOT/00158 dated 18/08/2018, hereby declare that the subject matter of my Ph. D. thesis entitled "***Agro-ecological studies on two selected Musa cultivars planted in cultivated and abandoned Jhum land of Mokokchung district, Nagaland***" is the record of original work done by me, and the content of this thesis did not form the basis of the award for any previous degree to me or to anybody else to the best of my knowledge. This thesis has not been submitted by for any research degree in any other University/Institute.

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CERTIFICATE

This is to certify that the thesis entitled "**Agro-ecological studies on two selected *Musa* cultivars planted in cultivated and abandoned Jhum land of Mokokchung district, Nagaland"** is a record of original research work carried out by Mr. Watitemjen under my supervision. He is a registered research scholar bearing the registration no: Ph. D./BOT/00158 dated 18/08/2018 of the Department of Botany and has fulfilled all requirements of Ph. D. regulations of Nagaland University for submission of thesis. The work is original and neither the thesis nor any part of it has been submitted elsewhere for the award of any degree or distinctions. The thesis is therefore forwarded for adjudication and consideration for the award of degree of Doctor of Philosophy in Botany Nagaland University.

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Watitemjen 17-04-2023

(Mr. Watitemjen)

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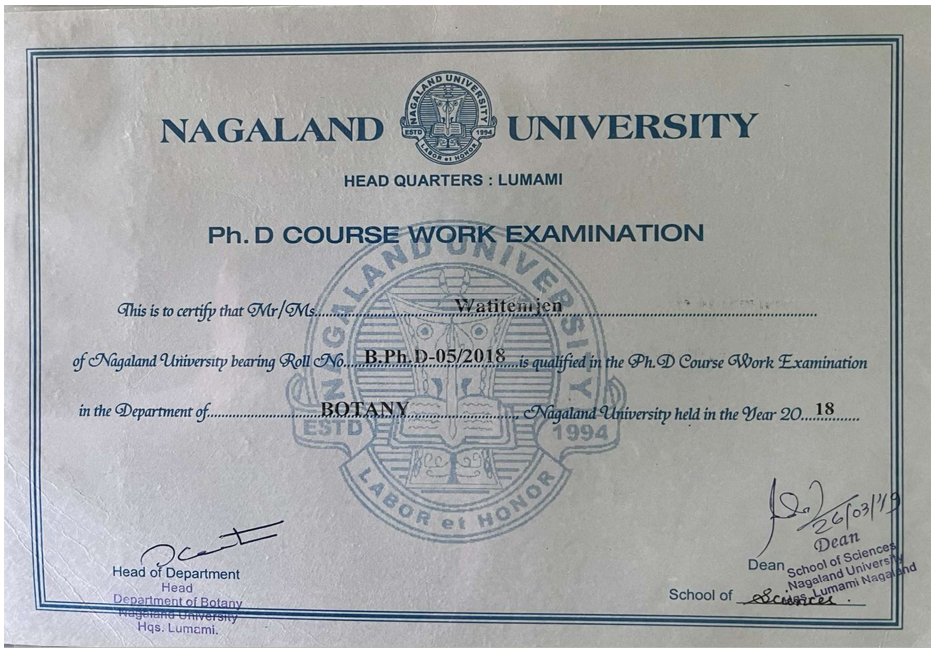

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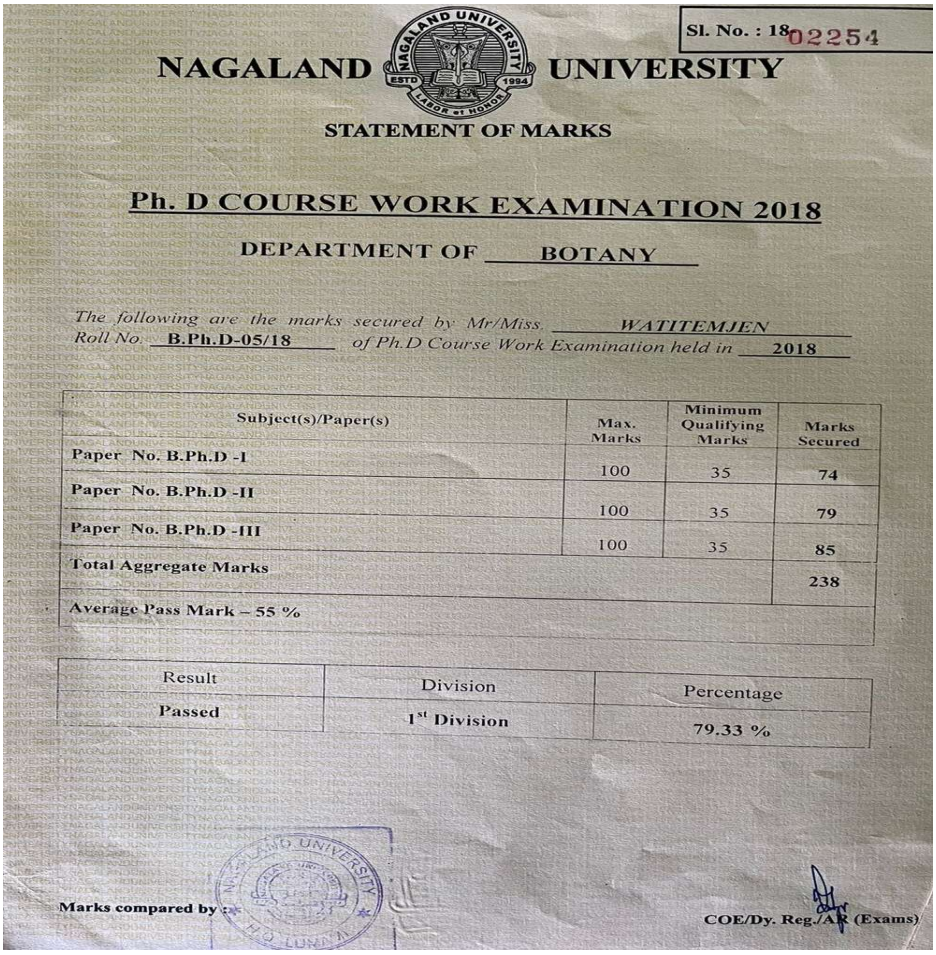

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Subject(s)/Paper(s)	Max. Marks	Minimum Qualifying Marks	Marks Secured
Paper No. B.Ph.D -I	100	35	74
Paper No. B.Ph.D -II	100	35	79
Paper No. B.Ph.D -III	100	35	85
Total Aggregate Marks			238
Average Pass Mark – 55 %			

Result	Division	Percentage
Passed	1st Division	79.33 %

Marks compared by :

COE/Dy. Reg./AR (Exams)

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CHAPTER-1

INTRODUCTION AND REVIEW OF LITERATURE

The term "Agro-ecology" originates from workers such as Bensin, Azzi, and Draghetti in the 1900s (Draghetti, 1948; Wezel *et al*., 2009). The current meaning of this science includes the following: Firstly, the ecology of the food system, i.e., the socio-economic and ecological aspects. Secondly, sustainable management of the food systems by applying adequate ecological concepts. And lastly, the application of research, education and action for sustainable agriculture systems (Francis *et al*., 2003; Gliessman, 2007; Gliessman, 2018). The Food and Agriculture Organization of the United Nations has proposed ten interlinked elements of agro-ecology for the implementation of sustainable food systems globally. This includes reusing, variety, collaborations, competence, resilience, co-creation, knowledge sharing, context features, responsible governance and creating an enabling environment (FAO, 2018). This system of agricultural practice attempts to optimize the various processes related to the complex ecological processes and minimize the dependency on external chemical input for creating a sustainable and efficient biological interactions in nature (Wezel *et al*., 2014). It is important to note that agro-ecology has grown from the regional scale to the global scale including the whole global food system and has been proposed as a modern solution to the problems of climate change and modern industrial agriculture associated with high chemical inputs (Wezel *et al*., 2009). Besides the ecological role, agro-ecology has a political aspect which includes strengthening of the economic viability of rural areas, support of diverse small scale food production, farmers, indigenous and traditional knowledge, local culture, identity and rights (Rosset *et al*., 2011; Nyéléni, 2015). The viability of agro-ecology in the modern world has been depicted in the global scale study by IAASTD (2009). They concluded that such practices not only provide equal or greater yield but also ensure livelihood security as compared to chemical based agriculture. Agro-ecology is vital for countries depicting low growth, decreased economic profits and distraction or migration of farmers to urban areas (Kareemulla *et al*., 2017). Farming practices that employ agro-ecological principles significantly increase the sustainability of agriculture in regions of India, wherein the extreme depletion of natural resources as well as the socio-economic aspects may be regulated. Such sustainable mitigation strategies and management ensure that the socio-economic and ecological challenges are met with.

Therefore, understanding the current socio-cultural conditions, ecological variables and stakeholder sensitization is critical.

Shifting cultivation, also called Jhum cultivation, Slash and Burn, Swidden or Rotational Bush Fallow Agriculture dominates agriculture in North-East India (Solo and Kikhi, 2021). This farming system originated around the Neolithic period (7000-8000 BC) and is believed to be one of the most ancient farming systems (Tripathi *et al*., 2017). Craswell *et al.* (1997) state that this method of farming form subsistence for at least half a billion people on the planet. The cycle of shifting cultivation begins with the removal and burning of vegetation to convert forest land into a cultivation area. Next, the soil goes through a cultivation period lasting one or more years, followed by a fallow period (15–20 years), which allows the soil to recover its nutrients (Mertz *et al*., 2009; Tripathi *et al*., 2017). Locally, this practice is called Jhuming and the cultivators are known as the jhumias (Devi and Choudhury, 2013). The perception of shifting cultivation as a primitive and economically inefficient agricultural production has been fundamental to many regions' land use management and policies (Maithani, 2005). However, in light of several recent studies, shifting cultivation is now deliberated as an ecologically and economically efficient agricultural practice, provided the crucial fallow period is maintained and is sufficiently long to enable soil restoration (Ramakrishnan, 1992; Cairns and Garrity, 1999; Van *et al*., 2008; Bruun *et al.,* 2009; Mertz, 2009; Ziegler *et al*., 2009). The problem hence arises as a many evidence regarding the shortening of the fallow periods from the optimal 20-30 years down to just 0–5 years is reported across S. E. Asia (Cairns and Garrity, 1999; Eastmond and Faust, 2006; Schmidt-Vogt *et al*., 2009). There are also concerning reports on the lowered fallow period, as short as three to one year within the North-East region of India (Bhuyan, 2019). Such practices negatively affect soil quality. This “soil quality” is defined as the capacity of the soil to function, sustain productivity, enhance water and air quality, and support human life and health (Karlen and Stott, 1994). There are also concerning reports on shifting cultivation contributing significantly to global warming (Fearnside, 2005). This is because the conversion of forest areas to arable land releases considerable CO_2 (Brown and Lugo, 1990).

Decreased fallow period reduces moisture content, increases evaporation and soil erosion, and diminishes plant nutrients (Greb, 1979). Such soil degradation leads to changes in the soil structure, reduces organic matter content and microbes, and ultimately

reduces productivity (Ziegler *et al*., 2009; Nielsen and Calderón, 2011). This reduction in productivity severely affects the soil's ability to aid in food production goals worldwide. Godfray *et al*. (2010) report that the global food demand will increase by as much as 50% before 2030. Therefore there is a demand for an enhanced understanding of the interchange between productivity and environmental health, wherein productivity should be increased and efficient use of natural resources should be ensured (Stoorvogel *et al*., 2004). Hence better-performing cultivars and sustainable farming methods to ensure the preservation of fragile soil ecosystems must be introduced in the agricultural domain (Tilman *et al*., 2002; Cassman *et al*., 2003). Such a method ensures that the challenges faced by food systems to adverse abiotic conditions are met sufficiently (Fresco, 2009). Efficient utilization of the resources available in nature and optimization of external inputs should be the primary goal of sustainable crop management. This can be assessed by monitoring productivity, yield stability, soil health, and fertility retention (Spiertz, 2012). It is thus crucial to evaluate soil quality by establishing specific indicators corresponding to land use and soil quality variations (Moffat, 2003). This ultimately aids in both sustainability and monitoring the productivity of a site (Andrews *et al*., 2002). Such monitoring and mitigation strategies ensure food security.

Bananas are herbaceous plants belonging to the genus *Musa*. They are characterized by the presence of a pseudostem or false stem (Sarma *et al*., 2020). The plant is utilized in several regions across the globe for its nutritional, dietary benefits, and traditional and medicinal purposes (Kumar *et al*., 2012). Another positive aspect of the plant is its ability to utilize several parts of its body which involves the utilization of its flower, fruit, pseudostem and fermented leaves as consumables (Sharma and Pegu, 2011). The banana leaves are also used as plates and construction materials; the stem generates yarn and textiles and are even used in soap and detergent preparation (Deka and Talukdar, 2007; Lal *et al*., 2017). As for their role in food production, nearly 5.6 million hectares of land employ banana cultivation around the globe (FAO, 2017). Banana cultivation is reported as one of the fastest-growing industry sectors, with growth as high as 20% per annum (GOK, 2008). This is because banana is a perennial crop that provides a steady source of income and food throughout the year for the household. In Nagaland, Murry and Das (2019) report an annual production of 53,900 MT of bananas on an area of about 6,690 acres. It is well established that agronomic practices alter soil properties, directly affecting the agronomic traits and proximate composition of fruit (Carl and Bierman, 2005; Martínez

et al., 2018; Ali *et al*., 2023). However, since the primary agriculture system in North-East India is shifting cultivation, the high requirement for water and nutrients required by bananas may not be sufficiently met (Nyamamba *et al*., 2020). Therefore, it is crucial to link the relationship between soil and productivity to ensure increased productivity and agricultural sustainability (Olivares *et al*., 2022).

The Eastern Himalayan region stretches from the Indo-Burma region to the Kashi Valley in Nepal, crossing China, Bhutan, and extending to North-east India (Chettri *et al*., 2010). Nagaland is a mountainous region in the corner of North-East India, bordering Myanmar, Assam, Arunachal Pradesh and Manipur, with 72% of the total arable land employing the practice of shifting cultivation (Solo and Kikhi, 2021). Rukuosietuo *et al*. (2014) report that 1,23,909 ha area, which accounts for almost 8% of the total area of Nagaland, employs shifting cultivation. Shifting cultivation forms the foundation of a community social structure employing community ownership and participation (Bhuyan, 2019). Jamir *et al*. (2014) comment that shifting cultivation under the region has not adopted alternative practices associated with land uses mainly because of two factors, i.e., this cultivation method forms the socio-cultural lifestyle of the region, and the second is the lack of other sustainable alternative means with regard to cost, yield, and lifestyle. State perspective and strategic plan of Nagaland (SPSP, n.d) report on the reduction of the fallow period (5 years or lesser) and the incorporation of the steep land use into Jhum lands. There are also reports on the practice of cassava plantations on fallow lands as a cash crop (Fermont, 2009; Temjen *et al.,* 2022). Such practices may negatively impact the soil recovery process. There is also a need to validate the selection of key soil indicators to monitor the soil under the region. Such a technique will aid in quick and resource-efficient monitoring of the various land use under the region. Additionally, there is a need for sustainable mitigation strategies to restore soil quality in the region and increase productivity to ensure food security. Keeping these points in view, this study attempts to observe whether different fallow periods significantly affect the agronomic performance of *Musa* cultivars. The study also aims to understand which soil factors affect the productivity of the selected *Musa* cultivars and the effects of different fallow practices on soil recovery.

Review of literature

A brief introduction on Musa

Musa, commonly called banana, is a monocotyledon herbaceous plant belonging to the *Musaceae,* order *Zingibiberales* (De Langhe *et al*., 1986). The genus *Musa* possesses two types of propagation: the triploid cultivars propagated through vegetative means and the diploid wild type capable of sexual recombination. The majority of the diploid *Musa* is endemic in South-east Asia, including India, and as such, is considered the central origin of banana (Simmonds, 1987). The present-day edible *Musa* cultivars are hybrids of two diploid *Musa* species, i.e., *M. accuminata* and *M. balbisiana,* with genotype AA and BB, respectively (Dodds, 1945). Such a condition leads to the formation of different combinations of cultivars such as AA, AB, AB, AAA, AAB, and ABB groups, with the triploid in particular desired due to their vigor and seedless nature (Simmonds, 1962). To aid with the taxonomic scheme, Simmonds and Shepherd (1955) introduced the three-tier system, i.e., species name followed by ploidy and genomic groups, which is based on morphological scores. These methods are extensively used to rapidly identify and evaluate crop improvement programs (Atom *et al*., 2015). Further, assessing *Musa* cultivars with large bunches, increased sucker production, enhanced fruit quality, and other desired agronomic traits that achieve the region's qualitative and quantitative requirements are vital in banana breeding goals (Brown *et al*., 2017).

With regards to their nutritional composition, banana contain sources of fructose, sucrose, acids such as ascorbic, citric, malic, and oxalic, protein as high as 210 mg/100g FW, phenolic compounds (0.9 mg GAE/g FW), carotenoids such as lutein, α-carotene, and β-carotene and high potassium content (450–467mgK) (Nguyen *et al*., 2003; Mura and Tanimura, 2003; Lee, 2008; Pareek, 2016). In addition, there are also reports on the antimicrobial properties of *Musa*. Workers (Asoso *et al*., 2016; Prakash *et al*., 2017) report on the antimicrobial properties of peel and fruit extract of *Musa* against bacteria such as *E. coli* and fungi such as *Aspergillus niger*. Regarding productivity, globally, India is the fourth largest banana exporter. Mehazabeen and Srinivasan (2020) attribute the high production rate to its low cost, availability throughout the year, and high nutritive composition. Regarding production, banana constitute almost 37 percent of the fruit production of India, a productivity of 30807 MT, and highest production under Madhya Pradesh. In Nagaland, Murry and Das (2019) report on the high net return and profitability of banana farming, but remarked on the high cost owing to increased labor charges and the region's unique geographic features. This highlights key agronomic and economic challenges associated with sustainable market opportunity in the region, especially in

Nagaland. The first is the ecological aspect, such as decreased fallow period, low-quality planting materials, and pathogens, while the economic aspect includes the increased input cost and unorganized farmer market (Côte *et al*., 2010).

Agro-ecology: Opportunities and challenges

Mertz *et al.* (2008) report that despite the numerous economic developments globally, millions still rely on shifting cultivation for their livelihood. An approximated area of 850 million ha of land under Africa, America and Asia employs one or the other form of shifting cultivation (FAO, 2005). Wezel *et al*. (2009) opine on the need for a paradigm shift in global mitigation strategies to tackle the ever increasing pressure on natural resources, loss of biodiversity, and climate change. Adequate understanding of the various agro-ecological processes can simultaneously tackle climate change problems and ensure sustainable resource utilization (Temegne *et al.,* 2021). This is achieved by implementing techniques such as increasing plant cover of the soil, adequate restraint and control of chemicals influx, increased organic inputs, sustainable utilization of bio resources, preserving soil fertility and simultaneously adhering to the socio-cultural and economic factors (Martínez, 2004; Gallardo-López *et al.,* 2018; Temegne *et al.,* 2021). Xuan *et al.* (2017) report on the urgent need for agro-ecological approaches to ensure sustainable forms of shifting cultivation under hilly terrain. These approaches to increase productivity include addition of organic matter, afforestation with short term crops, and regeneration of degraded land with cover species, introduction of cover trees to prevent erosion, living fences (*Randia* spp.), intercropping, and introduction of plants for quicker recovery of land under fallow. Regarding the country's ability to harness the benefits of agro-ecology in India, Costa and Pflaum (2015) report on certain limiting factors, namely: The rigid market ecosystem, environmental policy, inadequate information and agricultural research. The workers also suggest the immediate termination of genetically modified organism (GMO) trials and implementation of a large scale pilot study in the country (the study proposes at least 1 lac villages under the country be evaluated). The study also highlighted the potential of successful implementation of agro-ecology under the state of Jharkhan with increased productivity from 1 t/ha to 3-4 t/ha *via* implementation of System of Finger Millet Intensification (SFMI) for increased root growth. Regarding the potential implications of agro-ecology in the North-Eastern region, Amol *et al.* (2022) report on the lowered soil fertility and water content, high cost of chemical inputs and the need for

awareness on effective and sustainable adaptation strategies. Such problems in the North-East region may be tackled by the holistic approach of agro-ecology that mitigates the problems of modern agriculture, while simultaneously spreading awareness to the stakeholders. Siladitya *et al.* (2016) report on the varied agro-ecological zones of North-East India, with four distinct soils namely: Entisols, Inceptisols, Alfisols and Ultisols, and also the need for different strategies for each soil on a spatial and temporal scale. The worker also commented on the accelerated soil degradation under Jhum lands, with the highest degradation observed under Nagaland. Pandey *et al*. (2022) on the role of agro-ecological practice under Andhra Pradesh opined on the deep interconnection of socio-economic and agro-ecological factors in determining and conserving the biodiversity of the region. The workers, however, report that due to a lack of alternative means of fire-free farming in Jhum fields, the practice of seasonal burning of vegetation has lowered the effectiveness of the traditional agroforestry system and the principles of agro-ecology.

Agronomic traits and its relationship with soil

Uwimana *et al*. (2020) report on three essential traits to determine overall agronomic traits/performance of a *Musa*. These traits may be categorized as a). Vegetative growth: This includes vegetative traits such as plant height, girth, and number of suckers: b) Maturity: This includes the duration of the plant cycle regarding flowering and harvest: c) Fruit yield: This includes the overall yield of the plant. Such information establishes the fine relationship between the genotype and desirable phenotype. Van Leeuwen *et al*. (2004) remark on the need for a deeper investigation of the role of soil characteristics in determining agronomic traits and biochemical constituents of fruits. This is because agronomic traits are influenced by abiotic stress such as uneven precipitation, inadequate soil nutrient levels, unsuitable soil structure, and biotic stress such as invasive species, pathogens and pests **(**Cunningham *et al.*, 1992). Similarly, workers (Mohamed *et al*., 2018; Qiu *et al*., 2018; Zeng *et al*., 2018) report on the role of soil role of P (Phosphorus) and K (Potassium) levels in significantly affecting the agronomic trait of plants (fruit quality and yield). *Musa* cultivars under decreased soil moisture have been reported to prolong their vegetative phase significantly and display reduced hand production, size, and decreased fruit filling index (Uwimana *et al*., 2020). It is, therefore, essential to assess the after-effects of soil on the agronomic trait as the nutrient content, fibre, minerals and chemical compounds act as both sources of food and medicine (Yahia *et al*., 2019). Such interaction

between ecology and agronomy is therefore critical. This is because *Musa* cultivation is more attractive to local farmers considering the lower cost and labor requirement as compared to other main crops cultivated such as maize, rice, yam, cassava (Marriott and Lancaster, 1983). These information of the agronomic traits of parents is also vital for selection in crossing programs of *Musa* (Mattos *et al*., 2010). Such information also ensures in securing rural livelihood security and sustainable utilization of nature by increasing the dependency on Non-timber forest products (NTFPs) (Talukdar *et al*., 2021). Hence, it is vital to identify the factors that significantly affect productivity under different land use (Snook *et al*., 2005).

Mattos *et al.* (2010) report on the importance of inventorying of genetic resources of banana. Such methods are vital in the development of new hybrids and ensure suitable agronomic traits such as desired fruit quality. Dada *et al*. (2017) also report on the significant role of soil characteristics in determining agronomic traits and proximate composition of crops in the soils of Ibadan, Nigeria. The workers report that the number of leaves, plant height, growth, crude protein, crude fibre, and crude fat responded significantly (p=<0.05) to variations in soil properties. Such significant variation of vegetation has been attributed to increased uptake of soil N (Nitrogen), P, K (Carl and Bierman, 2005). Similarly, Ali *et al*. (2023), on the soils of Pakistan, attribute topography and edaphic factors as the primary agent responsible for the significant variation of crude fat, carbohydrate, protein and minerals in wild edible fruits. Nayak *et al*. (2020) report on the importance of agronomic evaluation of *Musa* cultivars with elite genotype for increased livelihood security under Orissa. The workers isolated genotype NRCB Selection-10 as an ideal candidate owing to its high yield, increased fruiting, resistance to wind, and thicker stem. Regarding the utilization of *Musa*, Kumari *et al.* (2022) on banana cultivars from Assam, India highlights the potential of banana as a multifunctional food owing to its high carbohydrate, ascorbic acid, antioxidant and fatty acid content. Sarma *et al.* (2020) also report on the high utilization of banana in Assam, ranging from cuisine, and utensils to rituals.

Effect of soil on proximate composition of *Musa*

The proximate composition of fruits includes moisture content, ash content, crude fat, crude protein, crude fibre, and total carbohydrate content (Islary *et al*., 2016). These are the structural components of food: carbohydrates and fats constituting the main form of

energy: moisture content determining storage and preservation: protein integral as the building block of life: and ash representing the mineral content (Onwuka, 2005; Yusuf *et al*., 2007). The assessment of such compositions enables researchers to evaluate the nutritional status of the fruits. This assessment of the different compositions of fruits regarding nutrition is extremely important in rural and tribal communities (Deshmukh and Waghmode, 2011). This is because, in poorer sections of the community, edible fruits are the major part of their nutrient and supplement (Eromosele *et al*., 1991). These fruits are also rich in vitamins, minerals, fat, protein and crude fibre (Ochokwu *et al*., 2014). In contrast, Perin *et al*. (2020) argue that soil factors interact significantly with fruit genotype and phenology. Therefore, the phenotypic plasticity of fruits regarding physiology and quality is also significantly correlated with soil (Wang *et al*., 2019). The presence of soil water and nutrients significantly affect the nutrient composition of fruits by altering the rate of nutrient transmission and transportation in plants (Hua *et al*., 2021). Hence, it is crucial to adequately evaluate the nutritional aspect of fruits regarding diet, agricultural strategy and food industry (Torres *et al*., 2000). Khawas *et al.* (2014) report on the effect of ripening with regards to biochemical compositions in *Musa*. The total carbohydrate content and moisture increased significantly with ripening which is associated with the biochemical changes during fruit maturation. Kookal and Thimmaiah (2018) report on the proximate composition of three *Musa* cultivars (Robusta, Nendran, and Njali poovan) from Kasaragod district of Kerala. The authors report on the increased moisture content, ash content, and protein content with the ripening of the fruit, while lipid and carbohydrates decreased with ripening. Such studies also highlight the need to assess and evaluate the proximate composition of the fruit at different ripening stages to expand the fruit's utilization under the region.

Shifting cultivation practices in North-East India

North-eastern India is home to a large number of indigenous communities called Scheduled Tribes inhabiting eight states, i.e., Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura (Marchang, 2017). Shifting cultivation has been practiced since time immemorial in the North-Eastern hills of India (Borthakur and Borthakur, 1992). Bhuyan (2019) reports that this practice is as old as human civilization and the practitioners of such farming systems are called *Jhumias*. This farming system forms the basis of the interlink-age between sociocultural, economic and

ecology among the states of North-East India (Kerkhoff and Sharma, 2006). Regarding land tenure systems in North-East India, the land can be owned by the community, kinship, clan, and individuals (Maithani, 2005; Marchang, 2017). This is highlighted under areas of Assam district, where the land is under the jurisdiction of the village head. In Manipur the land area is under the jurisdiction of the Manipur Land Revenue and Land Reforms Act (1960). The ownership of land is under the various clans under Meghalaya, and under Tripura and Nagaland community owns the land (Debbarma, 2008; Mukhim, 2008; Bhuyan, 2019). NSSO (2001, 2015) reports that among the North-Eastern states, Nagaland and Arunachal Pradesh have the largest proportion of households possessing land greater than four hectares amongst the states. Despite the un-uniformity in land tenure system and size, all areas follow a similar system of shifting cultivation: First is the selection of the fertile site for cultivation by the elders based on their rich traditional knowledge. Second is the clearing of the site where the entire community participates. Third is eventual sowing, which is usually accompanied by festivals that vary from tribe to tribe, and lastly, the fallow period, where the soil is allowed to recover (Hussain, 2004; Mertz, 2009; Bhuyan, 2019). This system of farming reflects the rich indigenous knowledge and the fine balance between productivity and ecological sustainability (Panda *et al*., 2016). The similarities among shifting cultivation practices across North-East India exist because farmers understand the various ecological processes and reflect their knowledge in the various agricultural activities (Altieri, 1989). NSSO (2001, 2015) reports that with the onset of the 2000s, shifting cultivation has moderately declined in all North-Eastern states expect in Nalagand. Pandey *et al.* (2019) also report on the attachment of shifting cultivation among the tribes of Nagaland to two factors, i.e., economic (inadequate infrastructure and consultancy services) and the socio-cultural aspect. Owing to this, it displays the inability of Nagaland state, in particular, to adopt a modern method of cultivation in its hills (Saikia, 1991). This also highlight the lack of alternative means of occupation for the indigenous inhabitants and the unique geography of the region (Marchang, 2017).

It is reported under Nagaland that the Konyak, Angami and Ao tribes utilize the bunding method, where the tree stump and rock barriers are employed to control the spread of fire (Senotsu and Kinny, 2016). Most Naga tribes usually alter the crop cultivation based on the demands of the market with site selection and burning during the months of February and March, followed by sowing around May (Solo and Kikhi, 2021). Based on the sociocultural practices, farmers in the state also do not practice excessive external

application of chemicals. This has led to Nagaland being the lowest consumer of fertilizer in the country (1.5 kg ha^{-1}) (FAI, 2004). However, one common trend in shifting cultivation across the North-Eastern states, in general, is the several reports on the reduction of fallow period (Debbarma, 2008; Marchang, 2017; Bhuyan, 2019; Borah *et al*., 2022; Temjen *et al*., 2022). This problem is reported to be associated with increased human population pressure, unsustainable farming methods, increased food demand, land development and village relocation policies (Hansen, 1998; Grogan *et al*., 2012). Unsustainable farming practises lead to irreversible damage to the eco-system, as such implementation of optimum fallow cycle is vital to improve soil health (Devi and Choudhury, 2013). Ehrlich and Holdren (1971) report the dangers arising simultaneously from both over exploration of bio resources and the rapid population increase. Such unsustainable practices eventually lead to environmental degradation (Agarwal, 1997; Jamir, 2021). It is also important to note that variation in species diversity varies as a forest recovers under fallow land (Scales and Marsden, 2008). Assessing the after-effects of such cultivation practices on the bio resources and implementing mitigation strategies to ensure sustainable livelihood among the indigenous inhabitants is vital (Borah *et al*., 2022).

Effect of shifting cultivation on soil properties

Shifting cultivation is reported to be sustainable, assuming three criteria are met: controlled population pressure, low chemical input, and an optimal fallow period (2008; Filho *et al*., 2013; Temjen *et al*., 2022). Pedroso-Junior *et al*. (2008) report that shifting cultivation may have both positive and negative impact of soil depending on the variation in the temporal and spatial scale. Nevertheless, the conversion of a forest into arable land *via* Jhumming has a significant impact on the soil property, plant diversity, and global greenhouse emissions (Chibsa and Ta'a, 2009; Don *et al*., 2011; Pringle *et al*., 2014; Schulz *et al*., 2016). Forest soil can regulate soil moisture, temperature, display higher net primary productivity *via* litter fall, better nutrient and exhibit efficient water regulation (Scharlemann *et al*., 2014). In an undisturbed forest area, nutrients are concentrated in the form of twigs, fine plant materials, branches and leaves. Such above ground biomass is readily lost following slashing, drying and burning of the soil and is reported to be the highest form of anthropogenic disturbance (Raison, 1979; Giardina *et al*., 2000). The concentration of P, N, K, and cations in soil are more prone to loss by erosion,

volatilization, and leaching after burning of the soil as compared to an undisturbed forest (Raison *et al*., 1985). Loss of litter fall directly affects the soil bulk density (BD) by lowering soil organic matter under soils of shifting cultivation. This leads to significantly higher BD under Jhum soils as compared to forest soils (Biswas *et al*., 2012). This increased BD in turn is reported to significantly reduce soil P and K levels **(**Agoume and Birang, 2009). Frequent burning of the soil and decreased fallow also alters the chemical composition of the soil organic matter (Fernandez *et al*., 1997).

Changes in the vegetation as an after-effect of agricultural practices negatively affect soil by decreasing the Carbon (C) and N stocks, which directly influences productivity **(**Solberg *et al*., 2004; Minasny *et al*., 2017; Yannick Ngaba *et al*., 2020). Arunrat *et al*. (2022) reported on the negative effects of shortened fallow period with regards to soil recovery. The study concluded that fire, in particular, significantly ($p \leq 0.05$) lowered the organic C and N content recovery under short fallow lands (1 year fallow) as compared to long fallow land (7 year fallow). Similarly, the conversion of forest to arable crops lands reduce soil carbon by as high as 25% and 30% of soil C under tropical areas (Don *et al*., 2011). Therefore, nutrient dynamics destabilize as the number of slash-and-burn and cultivation cycles intensifies (Gafur *et al*., 2003; Davidson *et al*., 2007). The soil quality undergo deterioration from the slashing and burning which continues till the onset of the fallow period (Osman *et al*., 2012). There is also changes in the soil structure with loss in fine soil, materials reduction and grain size modification, which negatively impact soil *via* increased leaching and erosion. Such changes alter the humidity, temperature, porosity and density of the soil ecosystem (Filho *et al.*, 2013). Another factor that determines soil structure under shifting cultivation is the number of crop cycles before the initiation of fallow. Adams (2000) reports on the association between increased cropping cycles and their impact of soil structure. A similar negative effect on the pH and nutrients of the soil is also displayed under increased cultivation cycles (Andriesse *et al*., 1987; Adams, 2000). Although soil recovery is affected by the cropping cycle, such negative soil changes are compensated by the fallow period, which allows the soil to recover its lost nutrient and vegetation (Pedroso-Junior *et al*., 2008). Filho *et al*. (2013) report a minimum of 10 years to prevent soil degradation and a maximum of 25 years for complete soil recovery. However, the problem is aggravated by the reduction of the fallow period in the North-Eastern region (Bhuyan, 2019; Borah *et al*., 2022; Temjen *et al*., 2022). Thus, the debate on the sustainability of shifting agriculture

and its impact on soils remains to be conclusive (Filho *et a*l., 2013). There is a need for an understanding of shifting cultivation practises under local context and caution should be taken about generalizations (Nath *et al*., 2022).

Thet *et al.* (2021) report that soil under traditional shifting cultivation practices significantly alter the various soil physiological process, stand structure and species diversity. The study remarks that the reduction of fallow significantly alters the C, and N content of soil affecting the diameter at breast height, height and basal areas of trees in the soils of Bago Mountains, Myanmar. Ziegler *et al*. (2012) report the severe reduction in above and below ground soil organic carbon (SOC) when shifting cultivation landscapes are converted to sedentary agricultural landscapes. Lawrence and Schlesinger (2001) comment on deep-rooted vegetation's role in restoring the soil P levels of shifting cultivation areas of West Kalimantan, Indonesian Borneo. The study report on the positive role of deep rooting and periodic death of plants as key contributors of P to the soil surface and deeper layers. Similarly, Mukul *et al*. (2022) report on the significantly higher SOC of older fallows in upland Philippines. They attributed this variation to increased litter fall, microbial activity, fine root biomass, and increased N deposition. They further report that the decreased SOC in younger fallows could be due to increased nutrient uptake by the regeneration forest. Rahman *et al.* (2012) studied on effects of increased deforestation and soil degradation due to the extensive shifting culture under regions of Eastern Bangladesh. They report a significant relationship between the adverse effects of land degradation due to high population pressure and the reduction of the fallow period with cycles of poverty in rural areas. Similarly, Saharjo (2007) reports that burning of soil during shifting cultivation adversely affected decomposed– hemic and sapric– peat with burn depth varying between 18 cm to 31.87 cm, resulting in a reduction of peat quantity or even total disappearance in Riau Province, Indonesia. Osman *et al*. (2012), on the studies on soils of shifting cultivation under Bandarban Hill District of Bangladesh, report on the elevated pH levels under shifting cultivation (4.47) as compared to natural forest lands (4.17). This increased soil pH is attributed to increased uptake of cations in the soil. Biswas *et al.* (2012) report on similar soil degradation under jhum lands. The shifting cultivation soil depicted increased BD (1.52 g cm^{-3}) as compared to forested sites (1.38 g cm^{-3}), lower total N 0.05% (SC) to 0.13% (forest) under hills of Chittagong, Bangladesh. Buraka *et al*. (2022) observed a reduction of 2.68x in the SOC levels of bare land as compared to forest land in

Southern Ethiopia. The reduction in the carbon stock is due to deforestation during the conversion of forest areas to cultivation areas.

Shifting cultivation in India is confined to mainly three regions, namely the North-East peninsula group, the Southern group and the North-East group, with the North-East group by far possessing the greatest and most detailed in the literature sources owing to its mountainous terrain and rich ethnic diversity (Kingwell-Banham and Fuller, 2012) As per Ninan (1992), Odisha and the North-Eastern states account for more than 90 percent of the total areas of shifting cultivation. Owing to this fact, there is scarce information on the practice of shifting cultivation regarding soil quality and productivity in other regions of India besides North-East India. Nonetheless, there are few literatures on the nature of shifting cultivation under regions of India. This practice of farming under India has many names, Zara and Erka (southern states), Vinga and Dhavi (Odisha), Kumari (Kerala), Batra (Rajasthan), Jhum (Assam), Adimolik' (Arunachal Pradesh), and Kumri' (Chennai) (Gogoi, 2020). Ninan (1992) reports on the spatial differences regarding shifting cultivation in India. The author reports that areas with low population employ shifting cultivation as the main form of occupation, while areas with higher population with diverse economic opportunities do not. Workers (Sethi and Naik, 2020) comment on the importance of socio-economic role of shifting cultivation among the indigenous inhabitants of South Odisha. Pradhan and Sahu (2022) similarly report on the importance of this farming practice regarding the Juangs tribal Groups in Keonjhar district, Odisha.

Shifting cultivation is widespread in the North-Eastern region, with approximately 8500 km^2 area employing this agricultural practice (Tiwari, 2018). Mishra (2022) attributes the intense shifting cultivation practices in the region to a lack of technical knowledge and poverty. The author also points to the rapid, unsustainable economic development and increased land pressure that reduces the fallow period which impacts the ecosystem resilience. Gupta (2000) reports that, out of the 19 tribal communities in Tripura state, 17 communities are entirely dependent on Jhumming. Nearly 223 km^2 of forest area is cleared annually and the fallow period has reduced from 25 years to 5-3 years. Bhuyan (2019) similarly remarks on the decreased fallow period, as short as five years, in North-East India. Kuotsuo *et al*. (2014) report that Nagaland, with an estimated area of 7,000 sq. km out of 16,579 sq. km, employs shifting cultivation. The authors report reduced fallow of five years or lesser which leads to leaching of soil nutrients, biodiversity loss and eventual

degradation. Nath *et al*. (2016) similarly report that the decreased fallow period has led to severe deforestation with highest forest cover lost in Nagaland (274 km^2) followed by Tripura, Manipur and Arunachal Pradesh, respectively. The workers also estimate a loss of about 60-70% soil nutrients, 100% increased runoff, 80% soil erosion, 75% loss of SOC under shorter fallow periods (3-5 years) vs long fallow periods (20 years). In the study of the effect of reduced fallow on soil, Meetei *et al*. (2017), report on the decreased SOC value of Jhum fields (19.08 g kg^{-1}) as compared with forest areas (23.68 g kg^{-1}) under Senapati district, Manipur, India. The authors attribute this to the decreased clay content and increased sand content, as the clay content value can significantly affect the active carbon pool (Hassink, 1994).

Effect of fallow period on agronomic performance

The relationship between fallow length and productivity continues to be a complex relationship owing to contrasting reports (Tian *et al*., 2005; Mertz *et al*., 2008). However, two common practices are accepted to negatively affect productivity. The first is the increased cropping cycle without a proper fallow period**.** This is mainly caused by weed intensification and increased soil nutrient deficiencies **(**Nye and Greenland, 1960; Johnson *et al*., 1991). The second factor influencing productivity is the fallow length. Fallow is reported to alter the agronomic performance of vegetation under Jhum lands. This increased productivity is due to the increased organic matter under longer fallow soil (Wapongnungsang *et al*., 2021). The decreased productivity under reduced fallow may be explained based on the decreased nutrient, increased leaching and volatilization and other soil alteration (Mertz, 2002). The period of an optimum fallow period for increasing productivity is however reported to vary across a spatial-temporal scale. Szott *et al*. (1999) report that fallow land shorter than 12 years may depict lower levels of cations, thereby limiting productivity. Beets (1990) report that a fallow period of 15-20 years is necessary for soil recovery. Whereas, there are also reports on the insignificant between fallow and productivity. Mertz *et al.* (2008) on their study of yield and productivity under shifting cultivation in Sarawak, Malaysia, found no significant correlation. They proposed that management practices namely burning and harvesting techniques, weeding practices, pest, and labour input, may significantly influence yield. Hence, the relationship between productivity and fallow varies as the spatial and temporal differs (Ruthenberg, 1980). It is, therefore, vital to establish a clear correlation between yield and fallow periods and

understand its strength and limitation to ensure sustainable ecological growth (Gilruth *et al*., 1995; Mertz *et al*., 2008).

. Patturajan *et al*. (2021) report on the increased clay content, higher microbial biomass and crop yield under fallow lands of Bhor tehsil, Pune District. Similarly, Wagalgave and Pise (2021) comment on the decreased N, P, and K content with an increase in the cropping cycle of shifting cultivation in Ambegaon taluka, Maharashtra. Deng *et al.* (2018) opine on the need of proper site selection for cultivation. The study of forests at Southern Yunnan Province, Southwest China, concludes that recovery of old tropical forest vegetation is slow, highlighting the need for the conservation of this ecosystem as recovery is affected by micro-climate, seed sources, soil quality and seed dispersal (Mertz, 2002). There are also reports on the decreased yield under shifting cultivation when the cycle increases, leading to soil quality decoration (Johnson *et al*., 1991). Padoch and Sunderland (2013) report on the restoration of social and ecological services *via* livelihood security and enhanced forest cover when the fallow period is maintained. Hiernaux *et al*. (2009) report on the decrease in yield of herbaceous plants such as millet or sorghum under shorter fallow lands (4 years) as compared to older fallow land (>9) in Southwest Niger. Similarly, Merang *et al*. (2019), report on the performance of three rice cultivar under shifting cultivation sites in Setulang village, North Kalimantan, Indonesia. All three cultivars showed increased productivity from 5 year fallow till the 15th year fallow, with an annual maximum production of 2.635 kg ha $^{-1}$, 2.208 kg ha $^{-1}$ and 2.075 kg ha^{-1}, respectively. Regarding the effect of fallow on productivity, Wapongnungsang *et al*. (2021) report on the increase in rice grain under fallow lengths of age 15, as compared to fallow land of age ten under Muallungthu village, Mizoram. They attribute the significantly increased yield under the longer fallow land (p=<0.01) to greater organic matter accumulation.

Effect of shifting cultivation on rhizospheric microbial population

The microbial community resides in the rhizosphere region and significantly affects their soil ecological habitat through various interactions (Saharan *et al*., 2011). Fungi, in particular, aid in the uptake of nutrients and slow mobility ions (P), and display higher resistance to both biotic and abiotic stress (Gazey *et al*., 2004; Silva-Sa´nchez *et al*., 2008). This mutual symbiosis in nature enables the mycelium to aid the root system by increasing uptake of nutrient which promotes growth (Raiman *et al.,* 2007). Burning of soil during

Jhumming significantly affect the ability of the microbial population concerning their function (Raison, 1979; Garcia-Oliva *et al*., 1999; Beschta *et al*., 2004). Non-fire resistant populations are significantly lowered under such practises as compared to forest lands (Gupta *et al*., 1986; Miah *et al*., 2010). Heating of soil above 127 C^0 sterilizes soil of all its resident microbes (Raison, 1979; Serrasolsas and Khanna, 1995). There is also an increase in the soil pH levels associated with burning. Such a condition leads to a decrease availability of nutrients and decreased rate of mineralization (Ohno and Erich, 1990; Miah *et al*., 2010). This significant decrease in nutrient concentrations is attributed to the decrease in total microbial activities in soil (Chen *et al*., 2004). Such microbial loss are reported to persist in the top soil layer for almost two years (Giardina *et al*., 2000). The workers attribute this phenomenon to a number of reasons: nature of the forest, increased severity of the fire, moderating influence of canopy on soil microclimate, and destruction of fine root biomass. The reduction in soil moisture post-burning and cultivation also significantly affects the size and diversity of the microbial population. A positive relationship exists between soil moisture and the microbial community (Dthar and Mishra 1987; Pritchett and Fisher, 1987). Miah *et al*. (2010) report that such farming activities permanently alters the natural vegetation, soil structure and ecological balance leading to drastic permanent changes in the soil microbial biota. The workers also report a significant ($p \leq 0.05$) reduction and even absence of fungal species on conversion of landscape to shifting cultivation areas. Their study reports a lower fungal population (92 to 139 CFU) as compared to the forest (147 to 180 CFU), with genera *Colletrotrichum* and *Fusarium*, being exclusive under forest soils of Chittagong Hill Tracts, Bangladesh. Similarly, Patturajan *et al*. (2021) report on the lowered total viable count (TVC) of the microbial population under soils of shifting cultivation as compared to Jhum fallows. In the study of fungal diversity on soils of banana, Shitole *et al.* (2019) report on the isolation of 22 fungal species, with higher species of *Aspergillus* (4) and *Rhizopus* (3), respectively. The author attribute this variation to soil properties such as pH, moisture and organic matter content. Similarly, Salve *et al.* (2019), on the soil of banana, isolated a total of 1354 fungal colonies belonging to over 35 fungal species in Jalgaon District, Maharashtra. Temjen *et al.* (2021) isolated 19 different fungal isolates from soils of banana plantation sites in Mokokchung, Nagaland. The workers report the genus *Aspergillus* as dominant due to better sporulation features of the genus. Dhruv *et al*. (2015), on different vegetation zones of Arunachal report that forest soils possessed higher fungal diversity as compared to Jhum lands owing

to higher litter at the former sites. The study also observed that species of *Cladosporium, Acremonium, Verticillium* and *Penicillium* dominated Jhum sites.

ORIGIN OF THE RESEARCH PROBLEM

Understanding agro-ecology at a regional level is essential to ensure optimum production and sustainable utilization of natural resources for the stakeholders. Shifting cultivation is strongly associated with the socio-cultural and economic aspect of the community in Nagaland, North-East India. Although this farming practice is the only means of livelihood security for a selected portion of the community, the concerns regarding the environmental disruption, soil health and quality must be monitored. The after-effects of the unsustainable means of cultivation through increased land pressure may lead to biodiversity loss and cripple the fragile ecosystem under the region. The large-scale deforestation, reduction in fallow and inadequate soil monitoring severely impact the productivity under soils of shifting cultivation in Mokokchung district, Nagaland, India. Such practices have accelerated nutrient leaching, soil erosion, disruption of the soil microclimate and watershed, destruction of habitat and loss of niche habitat. Further, the increased anthropogenic pressure on the soil also requires appropriate and adequate monitoring to ensure sustainable soil utilization. Although other studies have accessed the effect of fallow on soil, with the absence of work under the current region, there is a need to examine the relationship between fallow and productivity in Mokokchung district. This is more apparent as many studies depict the spatial and temporal variation concerning the effect of fallow on productivity. *Musa* cultivars play essential role in maintaining the livelihood securities of the inhabitants of the region. It is important to note that the various abiotic and biotic stresses affect the cultivars' productivity and nutrient composition. Such information can be obtained by understanding the various interaction between the *Musa* cultivars and the agro-ecological conditions of the region. Therefore, the present proposed research entitled ***"Agro-ecological studies on two selected Musa cultivars planted in cultivated and abandoned Jhum land of Mokokchung District"*** has been undertaken to understand the unique relationship between shifting cultivation and fallow on soil health, rhizospheric fungal diversity of the cultivars, and recording the agronomic performances and proximate composition of the *Musa* cultivars at the different study sites.

The following hypothesis were proposed.

1. Shifting cultivation and length of fallow period affect soil quality.

2. Shifting cultivation and fallow length alter the agronomic performance of *Musa* cultivars.
3. Shifting cultivation and fallow length alter the proximate composition of *Musa* cultivars.
4. Shifting cultivation and fallow length affect the rhizospheric fungal diversity and population of *Musa* cultivars.

SCOPE OF THE STUDY

The study is a novel attempt to explain the relationship between fallow and their effects on the agronomic performance of the two selected *Musa* cultivars under Mokokchung District, Nagaland. Despite the importance of soil characteristics in determining the fungal population and agronomic performance of the *Musa* cultivars, an investigation has yet to be carried out in the region. Therefore, the study aims to provide a comprehensive information on the quality of soil, identify the varied rhizospheric fungal diversity, and isolation of key soil indicators and factors that significantly contribute to the productivity of *Musa* cultivars under Jhum and fallow land of the region. Such information will assist in the sustainable utilization of the land resource and ensure its conservation. The data on the range of soil quality under the various land use will depict the effects of shifting cultivation and fallow on soil health. The agronomic performance of the Musa cultivars at the different fallow land will also enable categorizing the different soils for their optimum production under the region. The study also attempts to assess the impact of soil on the proximate composition of banana fruits. The study will also aid in isolating key soil indicators that contribute significantly to yield. Such data will enable the construction of local and regional soil quality maps. Similarly, the range of rhizospheric fungal diversity and population in the *Musa* cultivars at the different fallow land will be inventoried. The study also attempts to convey the idea of soil quality in simple terms to the local stakeholders by introducing soil quality index (SQI) to the indigenous inhabitants for dissemination of information. Overall an attempt has been made to provide an assessment of the soil quality under the region to aid in monitoring programs and aid in spreading awareness among the ethnic inhabitants and stakeholders

OBJECTIVES

1. To compare the agronomic traits of two *Musa* cultivars.

2. To estimate some selected biochemical composition of the *Musa* cultivars.
3. To compare the seasonal variation in physico-chemical parameters of soil.
4. To compare the diversity and population of rhizospheric soil fungi associated with *Musa* in both abandoned and cultivated Jhum land.

The thesis is organized as follows:

Chapter-1: Introduction and Review of literature

Chapter-2: Materials and methods

Chapter-3: Soil conditions of two *Musa* cultivars planted under different fallow periods

Chapter-4: Agronomic performance of *Musa* cultivars under different fallow period

Chapter-5: Proximate composition of *Musa* cultivars

Chapter-6: Effect of different fallow on rhizospheric fungal diversity

References

Appendices

CHAPTER-2

MATERIALS AND METHODS

2. 1 Description of the study site

Nagaland is a mountainous region in the corner of North-East India, bordering Myanmar, Assam, Arunachal Pradesh, and Manipur, and it is of critical importance for global biodiversity conservation (Myers *et al*., 2000). The region provides a strong potential for biodiversity benefits while mitigating climate change with a high emission mitigation potential (Murthy *et al*., 2013). Regarding Jhumming, almost 72% of the total arable land employs shifting cultivation, and the ethnic population in the rural areas depends on farming in Nagaland (Solo and Kikhi, 2021). Mokokchung district, Nagaland, India, ($94^0$32′39″E and $26^0$13′44″N, 1093 asml) has an area of 1,615 km² with the mountains covered by tropical semi-evergreen forest. The Ao communities dominantly occupy the land. The experimental sites were selected under Longsa village, Mokokchung district ($94^0$32′59.78″ E and $26^0$13′15.20″). This village is located on the southern end part of Mokokchung district, and is surrounded by Meyilong village in the North, Chubayimkum Village in the West, Sapoti Village in the Southern end and Mangakhi Village in its Eastern region. The region experiences a humid subtropical climate with an annual average rainfall of 2,500 mm. The Ombrothermic diagram of Mokokchung district of the study period i.e. January 2020- December 2021, during soil analysis is depicted in **Fig. 1** (source: The POWER Project, NASA). The practice of shifting cultivation has deep socio-cultural roots among the Ao tribal community in Mokokchung district. This is evident in the festivals associated with farming in the region. The first is the sowing festival called “Moatsu” which is celebrated on the completion of sowing. The second important festival of the Ao tribe is the “Tsungremong” or the harvest festival celebrated in the month of August. This festival, in particular, has its roots in Longsa village, with the first recorded celebration in this village. Therefore owing to its rich socio-cultural heritage, shifting cultivation has formed the central system of cultivation among the hills of Longsa Village, Mokokchung, Nagaland. This makes the village a good study area, as it possess a large number of fallow lands of varying ages and types. Therefore to assess the effect of shifting cultivation and fallow on soil and productivity, the present study selected 4 sites as briefly explained below with land use map in **Fig. 2** and the respective GPS coordinates as

shown in **Table 1**. The land use map was generated utilizing QGIS 3.16.16. All experimental sites were selected after consultation with the local villagers and landowners.

Fig. 1: Ombrothermic diagram of Mokokchung district during the study period (January, 2020-December, 2021)

Site JL: A Jhum land in its 3rd cycle of cultivation. The site was yet to start its fallow period during the study period. The major crop cultivation in this site consist of rice, maize, chilli, tomato, cucumber and cassava (**Plate I**).

Site AJL3: An abandoned Jhum land that was exposed to a similar cycle of cultivation like site JL (i.e., 3 cycles). The site had completed its 3rd year of fallow period. No anthropogenic intervention after initiation of the fallow cycle is reported. Dominant vegetation comprises mainly of herbaceous species of *Ageratum conyzoides, Eupatorium* sp.*, Erigeron Canadensis, Erechtites* sp.*, Ischaemum muticum, Galinsoga* sp.*, Macaranga* sp.*, Mucuna puriens, Mikiania scadens, Poa trivialis, Pteris vittata, Sonchus* sp.*, Thysanolaena maxima, and Thysanolaena* sp. **(Plate II**).

Site AJLB: An Abandoned Jhum land that has completed its 3rd cycles of cultivation. Similarly the site had completed its third fallow period. This site employs the traditional

soil restoration technique of bamboo stands (*Bambusa tulda* Roxb.) at the start of its first fallow period. The bamboo stands are also planted for their economic benefits. Bamboo stands are reported to display elevated nutrient levels (Zheng and Hong, 1998). The site consists of *Bambusa tulda* along with other associated species such as *Angiopteris evecta, Ageratum conyzoides, Artemisia vulagris, Eupatorium* sp.*, Spatholobus* sp.*, Thysanolaena maxima, Macaranga peltata, Persea fructifera, Pueraria* sp.*, Persicaria chinensis,* and *Sonchus* sp. **(Plate III).**

Site AJL12: This site was also exposed to three cycle of cultivation, and was currently in its 12 year of fallow. The site comprised of fallow vegetation with no anthropogenic interferences. *Albizia chinensis, Angiopteris* sp.*, Artemisia vulagris, Anthocephalus cadamba, Azadirachta indica, Macaranga peltata, Phyllanthus emblica, Polygonum molle, Persea fructifera, Sonchus* sp.*, Schima wallichi, Thysanolaena maxima* and *Terminalia myriocarpa* are the principal vegetative species at this site (**Plate IV**).

Table 1: Study sites selected under Mokokchung district with GPS coordinates

Site	Cultivation period	Fallow period	GPS	Elevation (AMSL)	Major vegetation
JL	3 years	NA	26^0 13′ 31.50″ N 94^0 32′ 22.220″ E	1058 m	3rd cycle cultivation of cassava monocropping
AJL3	3 years	3rd year of fallow	26^0 13′ 38.558″ N 94^0 31′ 50.190″ E	875m	*Ageratum* conyzoides, *Eupatorium* sp., *Erigeron Canadensis, Erechtites* sp., *Ischaemum muticum*, *Galinsoga* sp., *Macaranga* sp., *Mucuna puriens, Mikiania scadens, Poa trivialis, Pteris vittata, Sonchus* sp., *Thysanolaena maxima,* and *Thysanolaena* sp.
AJLB	3 years	3rd year of fallow	26^0 14′ 31.22″ N 94^0 31′ 44.122″ E	813 m	*Bambusa tulda, Angiopteris evecta, Ageratum conyzoides, Artemisia vulagris, Eupatorium* sp., *Spatholobus* sp., *Thysanolaena maxima, Macaranga peltata, Persea fructifera, Pueraria* sp., *Persicaria chinensis, Sonchus* sp.
AJL12	3 years	12th year of fallow	26^0 14′ 08.55″ N 94^0 32′ 28.45″ E	980 m	*Albizia chinensis*, *Angiopteris* sp., *Azadirachta indica*, *Macaranga peltata*, *Phyllanthus emblica*, *Polygonum molle*, *Persea fructifera, Sonchus* sp., *Schima wallichi, Thysanolaena maxima* and *Terminalia myriocarpa.*

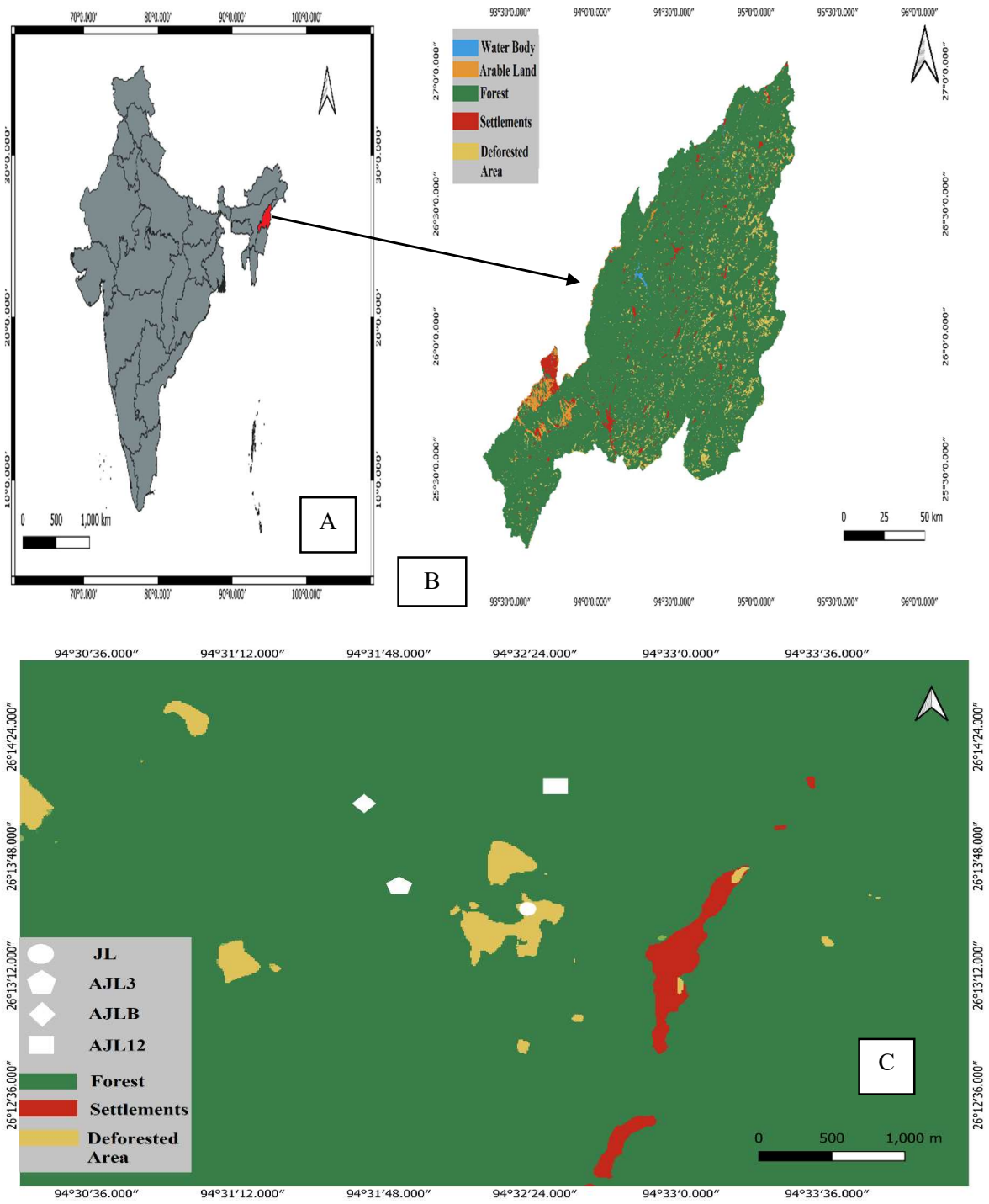

Fig. 2: Study map **A:** India map with Nagaland state highlighted in Red color. **B**: Nagaland Map depicting The land use. **C**: Land use map of Mokokchung district, Nagaland, displaying the four selected study sites (JL, AJL3, AJLB and AJL12)

Plate I: JL (Jhum land)

Plate II: AJL3 (Abandoned Jhum land 3)

Plate III: AJLB (Abandoned Jhum land with bamboo)

Plate IV: AJL12 (Abandoned Jhum land 12)

3.2 Soil physico-chemical parameter:

Soil analysis

To study the effect of fallow on soil, soil samples were collect layer wise at a depth of 0-10 cm, 10-20 cm, and 20-30 cm from each of the selected sites from spring (March-May, 2020), summer (June-August, 2020), autumn (September-November, 2020) and winter (December, 2020-February, 2021). All soil samples were collected from the site on tightly sealed polyether bags and transferred securely to the laboratory. Soil temperature was measured on-site utilizing a digital soil thermometer. All soil tests were performed by utilizing air-dried samples sieved through a 2 mm nylon sieve except for bulk density and soil moisture, which was determined by using fresh samples **(Table 2.1)**. All tests were performed in triplicates and expressed as mean±standard deviation. A brief explanation of the protocols for each test are as follows

1. pH and Electrical conductivity

To 50 ml of distilled water, 10 gm of soil samples was added into a conical flask and shaken for 30 minutes. Next, the supernatant is then transferred to a beaker and its pH and EC are recorded utilizing the HM Digital pH-200 and LMCM-20, respectively.

2. Soil Moisture

From the fresh collected soil samples, 50 gm were kept in an oven for 24 hours at 105^0C. Soil moisture in percentage is then obtained by utilizing the formula

$$\text{Soil moisture (\%)} = \frac{\text{weight of the oven dried soil}}{\text{weight of the fresh soil}} x\ 100$$

3. Bulk Density (BD)

Fresh soil samples were collected in a core sampler (10x10cm) and oven dried at 24 hours at 105^0C.

$$\text{Bulk density (gm/cm}^3\text{)} = \frac{\text{Mass of the dried sample}}{\text{Core sampler volume}}$$

4. Soil texture

20 gm of the soil samples were transferred to a 500 ml graduated cylinder. Next 50 ml of sodium hexametaphosphate and 10 ml of water is introduced into the cylinder. This mixture is then stirred for 5 minutes making the final volume to 500 ml. At the 48 second

mark, utilizing a pipette, 25 ml of the aliquot is removed. This aliquot is then placed under the oven at 105^0C with the help of an evaporating dish (labelled Silt+clay). The next aliquot is then collect at the 40 min from the upper 5 cm region of the suspension and then placed into the oven. The evaporating dish are then collected after 24 hours and weight. The soil texture is then calculated utilizing the formula

$$\text{Clay (\%)} = (20 \times \frac{\text{dried weight of the second aliquot}}{\text{weight the soil sample}}) \times 100$$

$$\text{Silt (\%)} = (20 \times \frac{[\text{dried weight of first aliquot} - \text{dried weight of the second aliquot}]}{\text{weight the soil sample}} \text{ x } 100$$

Sand (%) = 100 – (silt % + clay %)

5. Soil organic carbon (SOC)

1 gm of the soil sample is added to 10 ml of $K_2Cr_2O_7$ and 20 ml of conc. H_2SO_4 into a conical flask and allowed to react for 30 mins. To this mixture, 200ml of distilled water and 10ml of phosphoric acid is introduced. 1ml of indicator (diphenylamine indicator) is added and titrated against 1N ferrous ammonium sulphate (FAS). The end point of the titration process is when the mixture changes to green.

$$\text{Organic carbon (\%)} = \frac{A1-A2}{W} X\ 0.003\ X\ 100$$

*Where, A1 = volume of ml of 1N K2Cr2O7 utilized, A2 = volume of FAS used in titration, W = gm of soil sample.

6. Available Phosphorus (P_{av})

Reagents A and B are as follows.

$$\text{Reagent A} = \text{Ammonium molybdate A. R. (17.14 gm)} + \text{potassium antimonyl tartrate A. R. (0.392 gm)} + \text{Sulphuric acid (200 ml)} + \text{deionized water (850 ml).}$$

$$\text{Reagent B} = \text{L} - \text{Ascorbc acid A. R. (0.53 gm)} + \text{deionized water (5 ml)} + \text{reagent A (70 ml)}$$

In a centrifuge tube, 7 ml of Bray extracting solution (i.e. 2.22 g of Ammonium fluoride + 5 ml conc. HCl) and 1 gm of the soil sample is taken. The tube is then spun at 6000 rpm for 5 minutes. Dispense the supernatant (0.50 ml) and reagent B (2.0 ml) into a colorimeter

stand. This is then allowed to stand for half an hour. Next, prepare a standard solution from the P solution (2.50 mg/l) of concentrations 0.05, 0.10, 0.20, 0.30, 36, 0.40 and 0.50 mg/l. Finally, set the instruments instrument absorbance at 882nm and record. The phosphorus (available) is obtained by plotting concentration against absorbance.

$$\text{Available phosphorus (kg/ha)}=\frac{\text{Phosphorus concentration} \times \text{Dilution factor} \times 2.24 \times \text{aliquot utilized}}{\text{sample utilized}}$$

7. Available potassium (K_{ex})

50 gm of soil sample and 25ml of ammonium Acetate are transferred to an Erlenmeyer flask (150ml). After shaking it for 5 minutes in a mechanical shaker, it is then filtered through a filter paper (Whatman No. 1). Utilizing a flame photometer, the sample is adjusted to zero with blank. Next, for preparation of a standard graph, from the working K solution 0, 5, 10, 15, 20 and 25 ppm was prepared. The concentration of K in the sample is obtained by plotting against the standard graph.

$$\text{Available Potassium (kg/ha)}=\frac{\text{RxExtractvoumex2.24}}{\text{weight of sample}}$$

*Where, R=ppm of K value from the standard graph.

8. Total Nitrogen

The soil sample (1gm) is digested in conc. H_2SO_4 (10ml) and pinch of catalyst mixture (5:1 potassium sulphate and copper sulphate) under the Kelplus – KES 20 LR AL digestion System. Digestion occurs as the temperature is gradually lifted to 420^0C. The digestion is complete when the green color formation occurs inside the digestion tube. Next, upon cooling, the digestion tube is loaded in the Kelpus distillation unit. Boric acid (25ml) and methyl orange indicator are placed in a conical flask to collect liquid ammonia at the receiving end. Next, 40% alkali is added until it achieves a brown color. Finally, the flask is titrated against 0.1N HCl.

$$\text{Total Nitrogen (\%)}\frac{14.01 \times 0.1 \times (T1- \quad) \times 100}{S \times 1000}$$

*Where, 14.01 = molecular weight of ammonia

0.1N = normality of titrating solution

T1 = titration value of the sample

T2 = titration value of the blank

S = weight of the soil sample

9. Available Nitrogen (N_{av})

Soil samples (5gm), distilled water (20ml) and 0.32% $KMNO_4$ (25ml) are introduced into digestion tubes and fitted into the Kelplus distillation unit. To this 2.5% NaOH (25ml) *via* the distillation unit. At the receiving end of the distillation unit 2.5 % boric acid (25ml) is mixed with indicator i.e., Bromocresol green (0.3 gm), methyl red (0.2 gm) and 95% ethanol (400 ml) to receive the liquid ammonia from the receiving end. This is then titrated against 0.02N H_2SO_4.

$$N_{av}(Kg/ha)=14 \times (\text{Normality of the acid}) \times (\text{titrant value reading}) \times 2.24 \times \frac{106}{\text{sample weight} x\ 10000}$$

10. Cation Exchange Capacity

In a 40 ml centrifuge tube, add soil sample (45 gm) and Sodium acetate trihydrate (33 ml) and centrifuge at 33 rpm. Gradually pour the supernatant, and repeat with N Sodium acetate trihydrate (33 ml) at least four times and discard the supernatant liquid. Now add 95% ethanol (33ml) and centrifuge till a clear and decant supernatant is obtained. Repeat this step with 95% ethanol at least 3 more times. Now, replace the absorb sodium by utilizing 1N Ammonium acetate (33 ml) for three more times. Decant the three supernatant liquids into an 100ml volumetric flask and make the final volume with 1 N Ammonium acetate solution. Prepare a series of suitable Na standards by Diluting 2, 4, 6 and 8 ml of 250 ppm Na solution. Lastly add 1 N Ammonium acetate to each of the flask (100ml) to obtain 0, 5, 10, 15 and 20 ppm Na solution. Take the readings at Flame photometer.

CEC

$$(meq/100g)=\frac{meq}{L}\text{Na (from calibration curve)} x \frac{\text{Total volume of the extract (ml)}}{\text{weight of soil sample}} \ x \frac{100}{1000}\ x20$$

Table 2.1: Methods utilized in analysis of soil parameters in the present study

Soil parameters	Methods
pH	Digital pH meter
Electrical conductivity (EC)	EC meter
Soil moisture	Gravimetric method (Misra, 1968)
Clay content	Pipette method (Piper, 1942)
Bulk density (BD)	Core sampler method (Allen, 1989)
Soil organic carbon (SOC)	Walkley and Black method (1934)
Available nitrogen (N)	Kjeldahl method (1883)
Available phosphorus (P)	Bray's no. 1 extract method (Bray and Kurtz 1945)
Exchangeable potassium (K)	Photometric method (Trivedy and Goel 1986)
Cation exchange capacity (CEC)	Bower *et al*. (1952)
Total Nitrogen	(Kjeldahl, 1883)

Statistical analysis:

All statistical analyses for ANOVA and PCA were performed in SPSS version 26.0 (Statistical Package for the Social Sciences). One-way ANOVA was performed to compare the seasonal variation of soil and also to compare the means of each soil depth between the different sites that were statistically different at a 5% level by DMRT ($p<0.05$).

Soil quality index (SQI)

SQI could be defined as a minimum set of parameters that provides numerical data concerning the capacity of a soil to carry out one or more functions (Semy *et al*., 2022). The use of different individual soil parameters like organic carbon, clay, or single indices such as the metabolic quotient is a common approach utilized for the evaluation of soil quality. The main requirement for a soil property to be selected as a soil quality indicator is that it shows sensitivity to changes occurring within the soil function in question. In general, soil quality assessment is carried out by selecting a set of soil properties which are considered to be indicators of soil quality and selected as the minimum data set (MDS) and later, scores are assigned based on the computational data's with which the soil quality is measured (Vasu *et al*., 2016). The selection of a MDS is based on either expert opinion (subjective) or mathematical and statistical (objective) methods.

Minimum data set for soil quality index

To first determine the total data set (TDS), 10 soil parameters were isolated as per Semy *et al*. (2022). These include the following, pH, Moisture, Clay, BD, EC, CEC, SOC, P_{av}, K_{ex}, and N_{av}. For obtaining the MDS, A Principal Component Analysis (PCA) was performed. Factors obtained from the varimax rotation with eigenvalues of>1 that explained at least 5% of the variation in the data set were retained as the MDS for each site, respectively (Mandal *et al*., 2008). Pearson's correlation test was implemented to decrease redundancy among the highly weighted variables to aid in the MDS screening (Guo *et al*., 2018; Yu *et al*., 2018). After completion of screening, MDS with the highest scores were retained from each of the Principal Components.

Scoring of the indicators

Next, the scores of each indicator from the MDS were assigned a value that ranged from 0 to 1, through a linear scoring function (Raiesi, 2017; Yu *et al*., 2018) using two equations, i.e., lower is better (equation 1) and higher is better (equation 2). Meanwhile, for those parameters that possessed optimum range functions, indicators were tagged as good until a certain threshold level and as bad above the threshold level.

$$\mathrm{Lx} = \frac{\mathrm{Amin}}{\mathrm{A}} \qquad (1)$$

$$\mathrm{Lx} = \frac{\mathrm{A}}{\mathrm{Amax}} \qquad (2)$$

*Where: Lx =linear score,

A= value of the indicator selected in the MDS,

Amin= minimum values of the selected indicator

Amax= maximum values of the selected indicator.

Soil quality index generation: To obtain the SQI from the MDS, two equations were utilized, namely, the additive quality index and the weighted quality index.

1. Additive quality index (Nabiollahi *et al*., 2017).

$$\text{SQI(additive)} = \sum_{i=1}^{n} Si/n \qquad (1)$$

2. Weighted quality index (Raiesi, 2017).

$$\text{SQI(weighted)} = \sum_{i=1}^{n} WiSi \qquad (2)$$

Where: *n* is the number of variables retained in the MDS, *Si* represents the score of the variable in the dataset and *Wi* is the value of the weighted factor.

3.3 *Musa* cultivars selection and experimental design

Mokokchung is the second-largest producer of banana under Nagaland state (Murry and Das, 2019). To test the hypothesis of shifting cultivation and fallow length affecting productivity, sites of varying fallow periods were first selected. Further, a site with mixed bamboo plantation is also selected to access its role in soil restoration of the degraded Jhum sites. Two *Musa* cultivars were selected, i.e., Musa cultivar 1: Aot Mungo (Ao Naga) and *Musa* cultivar 2: Atsu Mungo (Ao Naga). The cultivars were selected based on their wide distribution, economic importance, and utilization by the people in the region. The selected *Musa* cultivars are also identified as Morpi (Manipuri-ABB) and Hei (Manipur-ABB), respectively in regions of North-East India (Pachuau *et al*., 2015; Atom *et al*., 2015; Singh *et al*., 2019). The mother plants of each *Musa* cultivars were first screened for possible infestation, disease and pests before sucker collection (Tumuhimbise and Talengera, 2018). The suckers of each cultivar were collected from a single farm to minimize variation. Care was taken to ensure that all suckers collected were uniform in size. Before plantation, each sucker was also treated with warm water to minimize weevils and nematode infestation (Uwimana *et al*., 2020). Eight suckers of each *Musa* cultivar were planted at each of the four experimental sites at a spacing of 5x5 m^2 (**Fig. 3**) at the four selected sites (**Plates-V**) at March 2020. The sites were cleared of its vegetation with minimal disturbance with no burning and surrounded by fencings to prevent any wild animal or anthropogenic disturbances. No chemicals or fertilizers were introduced at the study sites post plantation. The site was monitored weekly until the completion of its first cycle (i.e. planting to harvest).

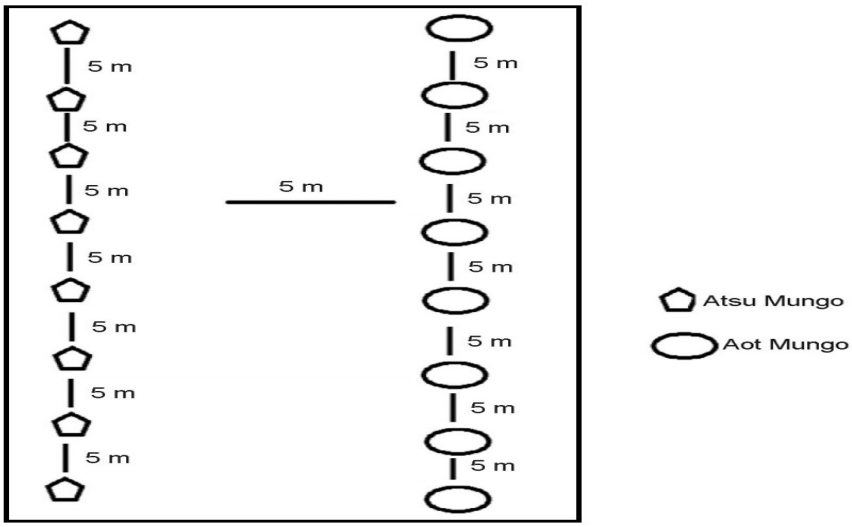

Fig. 3: Schematic representation of sucker plantation at the study sites

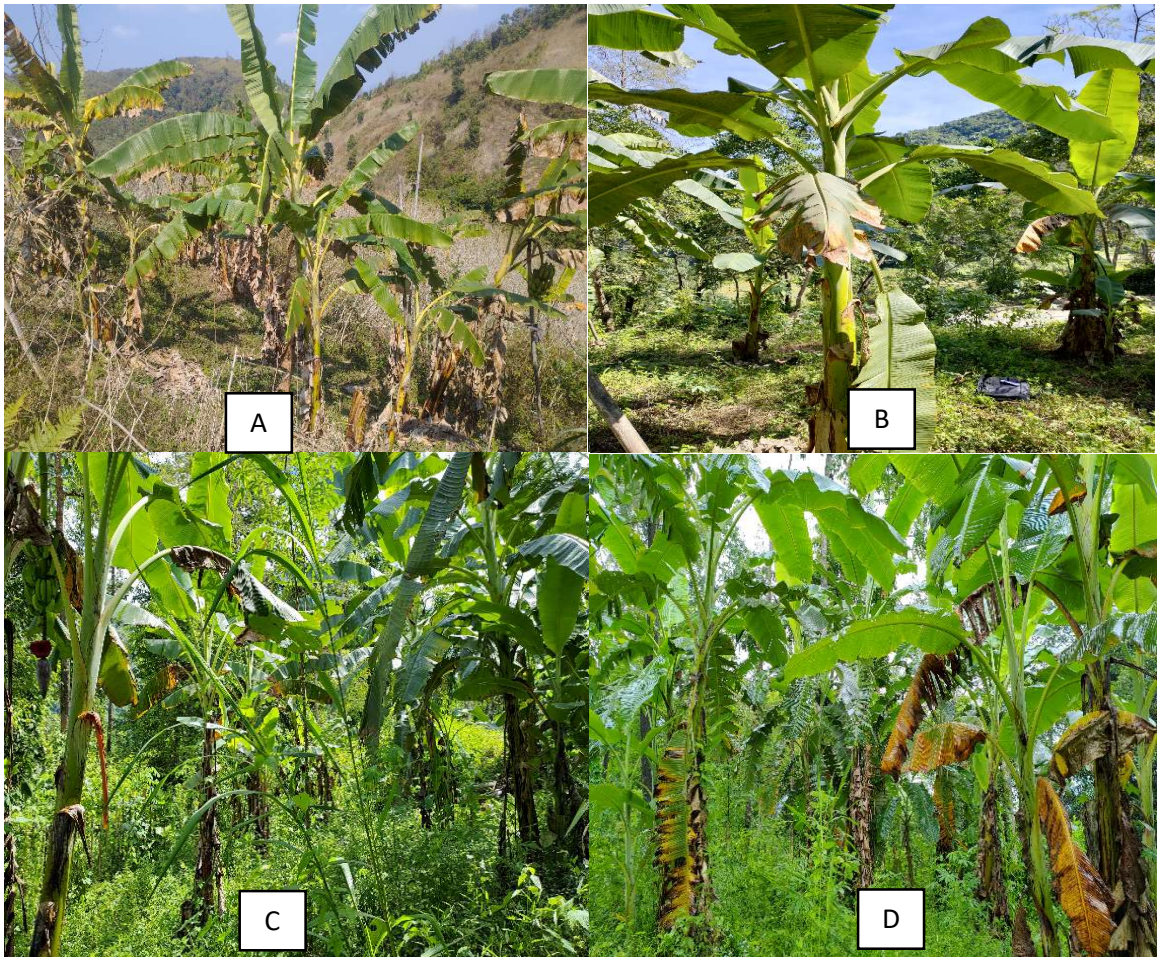

PLATE V: *Musa* cultivars at the selected sites **A:** JL (Jhum land). **B:** AJL3 (Abandoned Jhum land 3). **C:** AJLB **(**Abandoned Jhum land with bamboo). **D:** AJL12 (Abandoned Jhum land 12).

Agronomic performance

Suitable agronomic traits were selected from the method proposed by IPGRI-INIBAP/CIRAD (1996) and Uwimana *et al*. (2020), consisting of three broad categories, namely: Vegetative, maturity and fruit yield (**Table 2.2**).The expected fruit yield is reported as per Hauser and Van (2010). Relative yield was calculated as per Biswas *et al*. (2017)

$$\text{Expected fruit yield} = \frac{\text{B} \times 10,000 \times 365}{\text{Spacing} \times \text{PC} \times 1000}$$

*Where, B= bunch weight, spacing (5x5 m^2), PC= crop cycle in days

$$\text{Relvative yield (\%)} = \frac{\text{Yield of a sampling plot}}{\text{Maixmum yield of a sampling plot}} \text{x}100$$

Table 2.2: Agronomic traits selected for the study of agronomic performance of the two selected *Musa* cultivars

Agronomic trait	Parameters	Details
Vegetative	Plant girth (cm)	Measured at 1m, above ground during flowering
	Plant height (cm)	The distance from the ground to the angle made between the bunch stalk and bunch cover leaf
	Number of suckers	Number of suckers produced during flowering
	Number of functional leaves	Counted at flowering, leaves with at least 50% of the green area
Maturity	Plant cycle (days)	Number of days between harvest date and planting date
	Days to flowering	Number of days from planting to flowering
	Flowering to harvest(days)	Number of days from flowering to harvesting
Fruit yield	Bunch weight (kg)	Fruit weight at harvest
	Number of fruits	Number of fruits at harvest
	Number of hands	Number of hands during harvest
	Fruit filling index	Sum of bunch weight divided by the number of days from flowering to harvest
	Expected fruit yield(t ha−1 year−1)	Function of bunch weight, spacing and crop cycle from planting to harvest in cycle 1

Critical limits of soil quality indicators

The critical limits of soil quality indicators are defined as the optimum values required for the normal functioning of soil and its health for sustainable crop production (Biswas *et al*., 2017). The soil samples were collected as composite samples from each of the study site till the completion of the plant cycle and expressed as mean ± standard deviation. To obtain the critical limits, a simple linear regression between soil parameters and relative yield for obtaining the 40% and 80% of maximum possible yield was calculated. For this equation, the relative yield (X) = 40 and 80 are recorded and the corresponding value of soil indicators (Y) represents the upper and lower critical values, respectively. Soil values higher than the relative yield of 80% are categorized under the adequate category, between 41%-80% as moderate category, and finally <40% is considered as low category (Lopes *et al*., 2013).

3.4 Proximate composition of the two selected *Musa* cultivars

Both the fruit pulp and peel of the two selected *Musa* cultivars were analyzed for the proximate composition as per A.O.A.C (2000). The fruit was studied at two stages i.e., Green (Unripe) and yellow (Ripe). The fruit component consisted of unripe peel (Unp), ripe peel (Rip), unripe pulp (Unpu), and ripe pulp (Ripu). All test are conducted in triplicates and the values are expressed as mean ± standard deviation. The process are briefly explained as follows:

Sample collection and preparation

Freshly harvest ripe and raw samples were collected from the field and transferred to the laboratory. The samples were washed with deionized water, dried and made into powered form utilizing a mortar and pestle. The samples were then sieved through a 2 nm sieve and stored for analysis.

1. **Moisture content**

3 gm of sample were taken in clean weighted dish (A1) and the weights were recorded (A2). The sample and the dish were then transferred to an oven at 105^0C until a constant weight was obtained (A3). The percentage moisture was calculated as;

$$\text{Moisture (\%)} = \frac{A3 - A}{A2} X\ 100$$

2. **Ash content**

3 gm of sample were taken in clean weighted dish (A1) and the weights were recorded (A2). The sample and the dish were then transferred to a muffle furnace at 550^0C until fully ashed and weighed (A3)

$$\text{Ash (\%)}=\frac{A3-A1}{A2-A1} \text{X } 100$$

3. **Crude protein**

Crude protein content was estimated by 3 steps, namely digestion, distillation and titration. Take 0.5 gm of the sample $NaSO_4$ (10 gm), conc. H_2SO_4 (20ml) and $CuSO_4$ (1g) into Kjeldahl flask. Make final volume to 200 ml upon completion of digestion. Next, add 40% of 60ml (W/V) NaoH solution. The mixture is then attached to the distillation unit. Next 4% Boric acid (100 ml) and 2 drops of methyl red indicators are added the flask attached to the receiving end of the apparatus. On completion of distillation (pink color formation), the conical flask is removed from the distillation apparatus and titrated against 0.1m H_2SO_4.

$$\text{Crude Protein (\%)} = \frac{100\times \text{A} \times 0.0014 \times 6.25}{\text{weight of the sample}}$$

A =Titrant value.

4. **Fat content**

The fat content was determined as per Soxhlet extraction method (Pearson, 1976). 5 gm of sample is properly wrapped into a filter paper and kept in the Soxhlet apparatus. n-Hexane is kept in a conical flask where a heating mantle is applied onto it. The n-Hexane then evaporates and cools in the condenser and back to the conical flask. This process is repeated 9-10 times for maximum oil yield. The mixture containing oil is then transferred to a clean beakers where the remaining n-Hexane escapes, leaving behind only oil. The beakers were then re-weighed.

$$\text{Crude Fat (\%)}= \frac{A2-A}{\text{Sample weight}} \text{ x } 100$$

A1= weight of empty beaker

A2= weight of beaker + oil

A2-A1= weight of oil

5. Total carbohydrate content

The total carbohydrate was estimated as difference as per the nitrogen Free extract (NFE) method (Pearson, 1976).

Carbohydrate content (%)= 100- MC+AC+CF+CP+FC

MC = Percentage moisture content

AC= Percentage Ash content

CF = Percentage Crude fiber

CP = Percentage Crude Protein

FC = Percentage Fat content or Ether extract

3.5 Fungal diversity

Soil samples were collected seasonally from the rhizospheric region of the banana plantation sites during the study period. Samples were collected from five random location in the study site and combined to form a composite sample. Soils were then transferred to laboratory under sterile conditions and stored in 4^0C until analysis. Fungal species were isolated in Rose Bengal Agar and Potato Dextrose Agar (Himedia) plates supplemented with streptomycin sulphate following serial dilution method (Waksman, 1922). For soil dilution Selman and Waksman (1921) method was adopted. For this, 1 gm of soil sample was diluted in 10 ml of sterilized distilled water to make microbial suspension 10-1 to 10-5. Dilution of 10-2 to 10-5 were used to isolate fungi. One ml of dilution was taken from each serial dilution sample in triplicate form and transferred to plates of Potato Dextrose Agar (PDA) and Rose Bengal Agar (RBA). PDA and RBA media were supplemented with 0.03g/L streptomycin sulphate. Plates were incubated at 25 ± 1^0C for 5-7 days in dark. Colonies were inoculated in PDA and RBA plates and incubated at 25 ± 1^0C for 5-7 days. Morphology of the colony in plates was recorded. Microscopical examination consisted of preparing temporary lacto-phenol cotton blue slides and observation under compound microscope (Motic Model BA210LED). The fungi were identified with the help of literature (Gillman, 1957; Watanabe, 2002; Ho *et al*., 2003; Hauser, 2006; Nagmani *et al*., 2006; Webster and Weber, 2007; Afzal *et al*., 2013).

Percentage Contribution

The percentage contribution of the fungal colonies were estimated as per Salve *et al.* (2019). It is expressed in terms of colony forming unit (CFU) per gram soil of dilution factors and expressed as

$$\text{Percentage contribution}(\%) = \frac{\text{Total number of CFU of a species}}{\text{Total CFU of all species}} \text{x } 100$$

Fungal diversity indices

Fungal data obtained were then analysed in PAST (PAleontological Statistics) 4.03 for diversity indices. The diversity indices selected to access the impact of fallow on fungal population are briefly explained as follows

1. **Simpson's index of diversity (1-D)**

This diversity index represents not only the number of classes but also the proportion of classes (Simpson, 1949). The value ranges from 0 to 1, with 0 representing infinite diversity, and 1 representing no diversity. However, the Simpson's index of diversity is utilized instead of D, where 0 represents no diversity, and 1 represents infinite diversity.

$$D = 1 - (\frac{\varepsilon n(n-1)}{N(N-1)})$$

*Where, D= Simpsons diversity, n= total no of a particular species, N= total number of organism of all species.

2. **Pielou's evenness (J) index**

Pielou's evenness ranges from 0 (no evenness) to 1 (complete evenness), and evenness is high if all species have similar distribution (Pielou, 1969). It is represented by the formula:

$$E = \frac{H}{\ln S}$$

*Where, H is Shannon Weiner diversity, S is total number of species.

3. Berger–Parker index (D)

Berger-Parker dominance reports the proportional abundance of only the most abundant species in the population (Berger, 1970). Higher values of Berger-Parker indicate that the most common species dominate the community at the site.

$$D = \text{Nmax} / \text{N}$$

*Where, Nmax represents the number of individuals in the most abundant species, N represents the total number of individuals in the sample.

Canonical Correspondence Analysis

Canonical Correspondence Analysis (CCA) was performed as per Marín *et al*. (2017) and Liu *et al*. (2016). This statistical operation explores the relationship between the selected soil parameters and fungal population to assess the impact of soil on fungal distribution. PAST 4.03 was utilized to perform the CCA.

Phosphate solubilizing fungi (PSF)

The fungal isolates from the different study sites were screened for their ability to solubilize phosphate. Pikovskaya (PVK) agar (Himedia) was utilized for screening the PSF. PVK agar was sterilized at 121^0C and transferred to petriplates. Fungal isolates were transferred from pure culture to the PVK agar. The phosphate solubilization index (SI) was estimated on day five, ten and fifteen as per (Premono *et al.*, 1996) and is represented by the formula

$$\text{SI} = \text{Colony diameter} + \text{clearing zone diameter}/\text{Colony diameter}$$

CHAPTER-3

SOIL CONDITIONS OF TWO *MUSA* CULTIVARS PLANTED UNDER DIFFERENT FALLOW PERIODS

3.1 INTRODUCTION

Soil quality is said to determine the path of humankind. It is a cornerstone of environmental quality alongside air and water (Andrews *et al*., 2002). Increased soil quality forms the basis of increased agricultural productivity, resistance to soil degradation and its ability preserves it soil attributes (Reynolds *et al.,* 2009). However, with the onset of the modern century, there has been a sharp increase in the population. Such an increased population ultimately increases the demand for global food demand with increased dependence on mechanical and chemical inputs (Godfray *et al*., 2010). This has led to an alarmed increased in degradation of soil by erosions, acidification, increased salt content, and reduction in organic matter, loss of biodiversity and desertification in acute situations (Thakur *et al*., 2022). Thus, a need for a sustainable means of resource utilization, with farming systems that incorporates preservation of the natural services and systems is vital (Cassman *et al*., 2003). In stark contrast, with an increase in land pressure owing to an increase in population and lack of fertile lands, there is a practice of the decreased fallow period, as short as three to one year in the North-East region (Bhuyan, 2019). Such drastic reduction of fallow soil deprives the soil of its restoration and leads to significant changes in the soil (Bruun *et al.,* 2009). Such change ultimately changes the soil chemistry leading to reduced yield and affecting livelihood security (Ziegler *et al*., 2009, Godfray *et al*., 2010; Nielsen and Calderón, 2011). These changes in the soil property due to Jhumming also significantly alter the soil microbial diversity and functioning. Rampant soil degradation leads to uneven distribution of microbes, wherein the population that can withstand the high level of anthropogenic disturbance becomes dominant. Sensitive microbial populations in the rhizosphere are reduced or, in severe cases, eradicated (Beschta *et al*., 2004; Miah *et al*., 2010). These changes ultimately influence the nutrient concentration and rate of mineralization processes in the soil (Miah *et al*., 2010). Unsustainable changes in the soil and microbial communities are reported to negatively affect banana production industry by lowering and reducing yield (Van Asten *et al.,* 2004). As banana production is vital for ensuring livelihood security for the indigenous inhabitant

of Nagaland, regular monitoring of soil is crucial to ensure optimum and sustainable production (Murry and Das, 2019). This is essential, considering the contrasting reports on the relationship between soil fertility and banana production (Gold *et al*., 1999; Tushemereirwe *et al*., 2001).

Reduction of crop productivity is linked to many factors during shifting culture, including changes in soil structure, increased bulk density, decreased conductivity, imbalanced nutrients, and reduced organic matter, a direct means of assessment of soil quality is rather challenging. As such, a statistical method for soil quality estimation has been developed by Andrews and Carroll (2002), i.e., Soil Quality Index (SQI). The SQI is a statistical technique incorporating intricate soil data to produce a simple numerical value that ranges from 0-1. A higher value denotes a higher soil quality, and vice versa (Mukherjee and Lal, 2014). Creating such numeric values enables information dissemination to stakeholders and researchers alike (Mukhopadhyay *et al.*, 2016). The SQI is especially helpful in creating awareness among the indigenous inhabitants who are generally from a poorer economic section (Temjen *et al*., 2022). The utilization of the SQI also enables the formation of a minimum data set (MDS) of soil quality indicators. Such MDS consists of key soil quality indicators selected from the total data set (TDS) of soil parameters (Nabiollahi *et al*., 2017; Raiesi, 2017). Such tools significantly reduce soil monitoring programs' workload, cost, and resources (Temjen *et al*., 2022). SQI assists not only in monitoring the productivity of a site but also contributes significantly to the myriad of sustainable management goals (Andrews *et al.*, 2002), there is a need to generate a unique SQI that is appropriate for the region. SQI thus functions as a decision-making tool that aids in forming policies and multi-decision making (Karlen and Stott, 1994). Soil health monitoring is vital to ensure sustainable utilization and also ensure livelihood security in the region. Keeping in view the temporal and spatial variation of soil properties, this chapter attempts to assess whether the fallow period significantly affects soil health in *Musa* plantation sites. The study also attempts to generate SQI for the different sites to aid in efficient and rapid monitoring of land use.

3.2 RESULTS

3.2.1 Seasonal variation of soil properties

The result of the one-way ANOVA depicting the seasonal variation of soil variables among the sites is presented in **Table 3**. The seasonal variation of soil physico-chemical properties under the study sites are presented in **Appendix I**.

JL: Significant variation of pH was reported at 0-10 cm and 20-30 cm layers (p=<0.001; p=0.048), with lowest value of pH recorded at winter (5.4±0.04), while highest value was observed at autumn (5.9±0.10) as shown in **Fig. 4.1**. EC values varied significantly seasonally across all depth (p=<0.001) with lower values during winter and higher values during summer (**Fig. 4.2**). SOC content varied significantly only at 0-10 cm depth (p=0.042), with higher SOC values during autumn and lower SOC values during winter (**Fig. 4.3**). A similar observation was observed for BD, moisture, N_{av}, K_{ex}, and P_{av} with significant variation across all soil depth (**Fig. 4.8**, **Fig. 4.7**, **Fig. 4.4**, **Fig. 4.5** and **Fig. 4.6)**. Lower values of N_{av} (146.00±9.8 Kg ha^{-1}) was observed during the colder season i.e., winter (20-30 cm), while the higher value was observed during autumn. Similarly, the highest K_{ex} value and P_{av} value was observed during autumn and summer respectively, while lowest values were reported during winter. Moisture similarly was reported to be highest during autumn and lowest during winter. An opposite trend was reported for BD with higher values (2.88±0.05 g cm^{-3}) reported during winter and lower values during spring. The clay content (**Fig. 4.9)** and CEC (**Fig. 4.10)** displayed significant variation across all soil depths with higher values during autumn and lower values during winter. Total nitrogen varied significantly across all depths at JL (**Fig. 4.11)**. Higher values of TN was observed during autumn while minimal value were reported during winter. Sand (**Fig. 4.12)** and silt content (**Fig. 4.13)** varied significantly across all soil layers. Higher values of sand was recorded during spring and minimal values during autumn. Silt depicted higher values during winter and lower values during summer, respectively.

AJL3: pH values varied significantly between the 10-20 cm (p=<0.001) and 20-30 cm (p=0.003) depth (**Fig. 4.1)**. Lower pH value were observed during spring (5.0±0.16). EC values varied significantly seasonally across all depth (p=<0.001) with lower values during winter and higher values during summer (**Fig. 4.2**). A similar trend was reported for SOC (**Fig. 4.3**), N_{av} (**Fig. 4.4**), K_{ex} (**Fig. 4.5**), P_{av} (**Fig. 4.6**), BD (**Fig. 4.8**), CEC (**Fig. 4.10**), TN (**Fig. 4.11**), sand (**Fig. 4.12**), silt (**Fig. 4.13**) and moisture (**Fig. 4.7**) with

significant seasonal variation across all soil depths. SOC was higher during summer season (2.81±0.24 %) and lowest during winter (1.40±0.05 %). Moisture, N_{av}, K_{ex} and P_{av} displayed maximum values during autumn and lower values during winter, respectively. BD was highest during winter (1.93±0.03 g cm^{-3}) and lowest during summer (1.22±0.18 g cm^{-3}). CEC displayed higher values during summer and lower values during winter. TN displayed higher values during autumn and lower values during winter. Clay content varied significantly at the 0-10 cm depth only (p=<0.001), with lower values during spring and higher values during autumn, respectively.

AJLB: pH varied significantly at the 0-10 cm (p=0.002) and 10-20 cm (p=<0.001) depths for AJLB. The lower values were recorded during winter (4.5±0.02) while higher values were recorded during autumn (5.39±0.05), respectively (**Fig. 4.1**). In contrast EC varied significantly across all soil depths (p=<0.001) with higher values during summer and lower values during spring (**Fig. 4.2**). Similarly, SOC content varied significantly across all depths with highest value of SOC was recorded during summer (3.26±0.16 %), and minimal values recorded during winter (2.08±0.91%) as shown in **Fig. 4.3**. N_{av} (**Fig. 4.4**), K_{ex} (**Fig. 4.5**), P_{av} (**Fig. 4.6**), Soil moisture (**Fig. 4.7**), BD (**Fig. 4.8**). TN (**Fig. 4.11**), sand (**Fig. 4.12**), silt (**Fig. 4.13**) displayed significant variation across all soil depths during the study period. Maximum values of moisture, CEC, TN, N_{av}, K_{ex}, and P_{av} were observed during autumn, while lower values were recorded during winter. In contrast, clay content (**Fig. 4.9**) and CEC (**Fig. 4.10**) varied significantly at the 0-10 cm depth only (p=0.048; p=0.021, respectively). Maximum value of clay was recorded during the summer season (33.2±5.17 %), while minimal values was recorded during winter (26.8±3.58 %). CEC was recorded to be highest during autumn (29.28±3.6 meq$100g^{-1}$) and lowest during winter (23.44±2.7 meq$100g^{-1}$), respectively.

AJL12: pH values and EC values varied significantly across all soil depth across the seasons during the study period (**Fig. 4.1** and **Fig. 4.2**). SOC varied significantly only at the 20-30 cm depth (p=0.040) as shown in **Fig. 4.3**. Maximum SOC values was reported at autumn, with minimal value recorded during winter. It is reported that N_{av} (**Fig. 4.4**), K_{ex} (**Fig. 4.5**) and P_{av} (**Fig. 4.6**), BD (**Fig. 4.8**), CEC (**Fig. 4.10**), sand (**Fig. 4.12**), and silt content (**Fig. 4.13**), varied significantly across all soil depths during the study period. Moisture content was significant only for the 0-10 cm (p=0.001) and 10-20 cm (p=0.033) depth. The higher moisture content was reported during autumn while lowest was recorded

at winter (**Fig. 4.7**). Clay content varied significantly at the 10-20 cm depth (p=0.041), with maximum value during autumn (37.2±0.71%), and minimal at winter (30.8±1.22%) as shown in **Fig. 4.9**. The TN value ((**Fig. 4.11**) varied significantly across the soil depth during the study period.

Table 3: Result of One-way ANOVA with *p* and F values displaying the seasonal variation of soil parameters at the selected study sites

		SCS		AJL3		AJLB		AJL12	
Parameters	**depth (cm)**	***P-value***	**F-value**	***P-value***	**F-value**	***P-value***	**F-value**	***P-value***	**F-value**
CEC	0-10	**<0.001**	23.53	**0.013**	6.89	**0.021**	5.74	**0.002**	13.62
	10-20	**0.009**	8.007	**0.006**	9.20	0.909	.177	**<0.001**	21.92
	20-30	**0.002**	13.07	**<0.001**	35.46	0.570	.716	**<0.001**	22.19
EC	0-10	**<0.001**	31.7	**<0.001**	406.39	**<0.001**	21.62	**<0.001**	38.60
	10-20	**<0.001**	77.03	**<0.001**	199.3	**<0.001**	24.28	**<0.001**	28.67
	20-30	**<0.001**	64.79	**<0.001**	424.06	**<0.001**	30.49	**<0.001**	21.42
Moisture	0-10	**<0.001**	124.39	**<0.001**	307.39	**<0.001**	163.67	**0.001**	14.14
	10-20	**0.001**	17.35	**0.002**	13.81	**<0.001**	35.97	**0.033**	4.87
	20-30	**<0.001**	22.977	**<0.001**	20.31	**<0.001**	81.51	0.472	.925
P_{av}	0-10	**<0.001**	74.04	**<0.001**	59.54	0.110	2.78	**0.001**	18.75
	10-20	**<0.001**	126.963	**<0.001**	75.36	**0.001**	15.36	**0.002**	12.15
	20-30	**<0.001**	45.826	**0.003**	11.92	0.298	1.454	**0.002**	12.00
K_{ex}	0-10	**0.001**	18.13	**<0.001**	30.90	**<0.001**	93.74	**<0.001**	88.60
	10-20	**0.016**	6.43	**0.001**	17.85	**<0.001**	121.84	**<0.001**	26.89
	20-30	**<0.001**	40.61	**<0.001**	33.66	**<0.001**	28.39	**<0.001**	120.27
N_{av}	0-10	**<0.001**	125.01	**<0.001**	184.34	**<0.001**	36.18	**0.004**	10.29
	10-20	**<0.001**	113.57	**0.001**	16.22	**<0.001**	33.43	**<0.001**	26.15
	20-30	**0.001**	16.19	**<0.001**	16.91	**<0.001**	37.18	**0.003**	11.02
BD	0-10	**0.040**	4.45	**0.009**	7.73	**<0.001**	19.74	**0.014**	6.77
	10-20	**<0.001**	151.94	**0.004**	10.54	**0.003**	10.78	**<0.001**	30.24
	20-30	**<0.001**	184.73	**<0.001**	25.84	**0.001**	14.12	**<0.001**	55.03
SOC	0-10	**0.042**	4.40	**<0.001**	48.84	**0.001**	16.18	0.173	2.14
	10-20	0.183	2.06	**0.001**	16.38	**<0.001**	27.83	0.233	1.75
	20-30	0.385	1.15	**0.001**	17.68	**0.047**	4.17	**0.040**	4.46
Clay	0-10	**0.001**	15.21	**<0.001**	27.95	**0.048**	4.13	0.150	2.33
	10-20	**0.040**	4.47	0.371	1.19	0.057	3.84	**0.041**	4.45
	20-30	0.120	2.64	0.195	1.98	0.208	1.89	0.561	.732
pH	0-10	**<0.001**	22.96	0.148	2.35	**0.002**	13.72	**0.034**	4.76
	10-20	0.235	1.745	**<0.001**	41.24	**<0.001**	22.57	**0.017**	6.32
	20-30	**0.048**	4.12	**0.003**	10.85	0.355	1.24	**0.014**	6.78
TN	0-10	**0.002**	13.772	**<0.001**	210.39	**<0.001**	210.39	0.24	5.54
	10-20	**0.014**	6.651	**0.005**	9.52	**0.005**	9.52	0.20	5.95
	20-30	**0.006**	8.85	**<0.001**	25.23	**<0.001**	25.34	0.941	0.128
Sand	0-10	**<0.001**	26.59	**<0.001**	16.76	**0.001**	16.76	**<0.001**	332.3
	10-20	**<0.001**	51.39	**<0.001**	18.83	**0.001**	18.83	**<0.001**	319.9
	20-30	**00.15**	6.59	**0.002**	13.58	**0.002**	13.58	**<0.001**	146.03
Silt	0-10	**<0.001**	23.32	**<0.001**	68.087	**<0.001**	65.087	**<0.001**	461.59
	10-20	**0.001**	18.376	**<0.001**	40.39	**<0.001**	40.396	**<0.001**	66.23
	20-30	**<0.001**	41.842	**0.002**	12.485	**0.002**	12.45	**<0.001**	93.64

Bold font indicates a significant result (p<0.05).

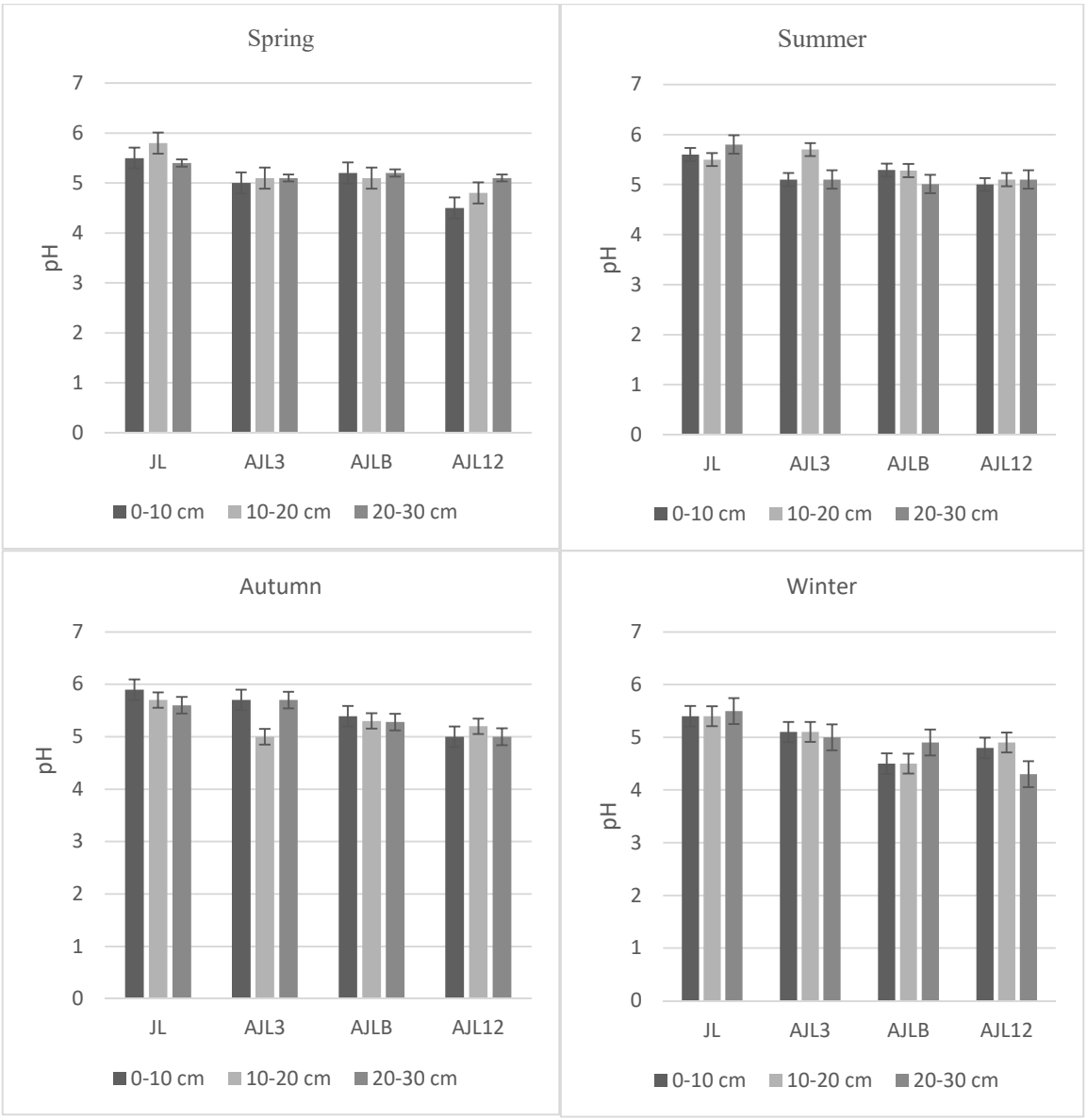

Fig. 4.1: Seasonal variation of pH across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

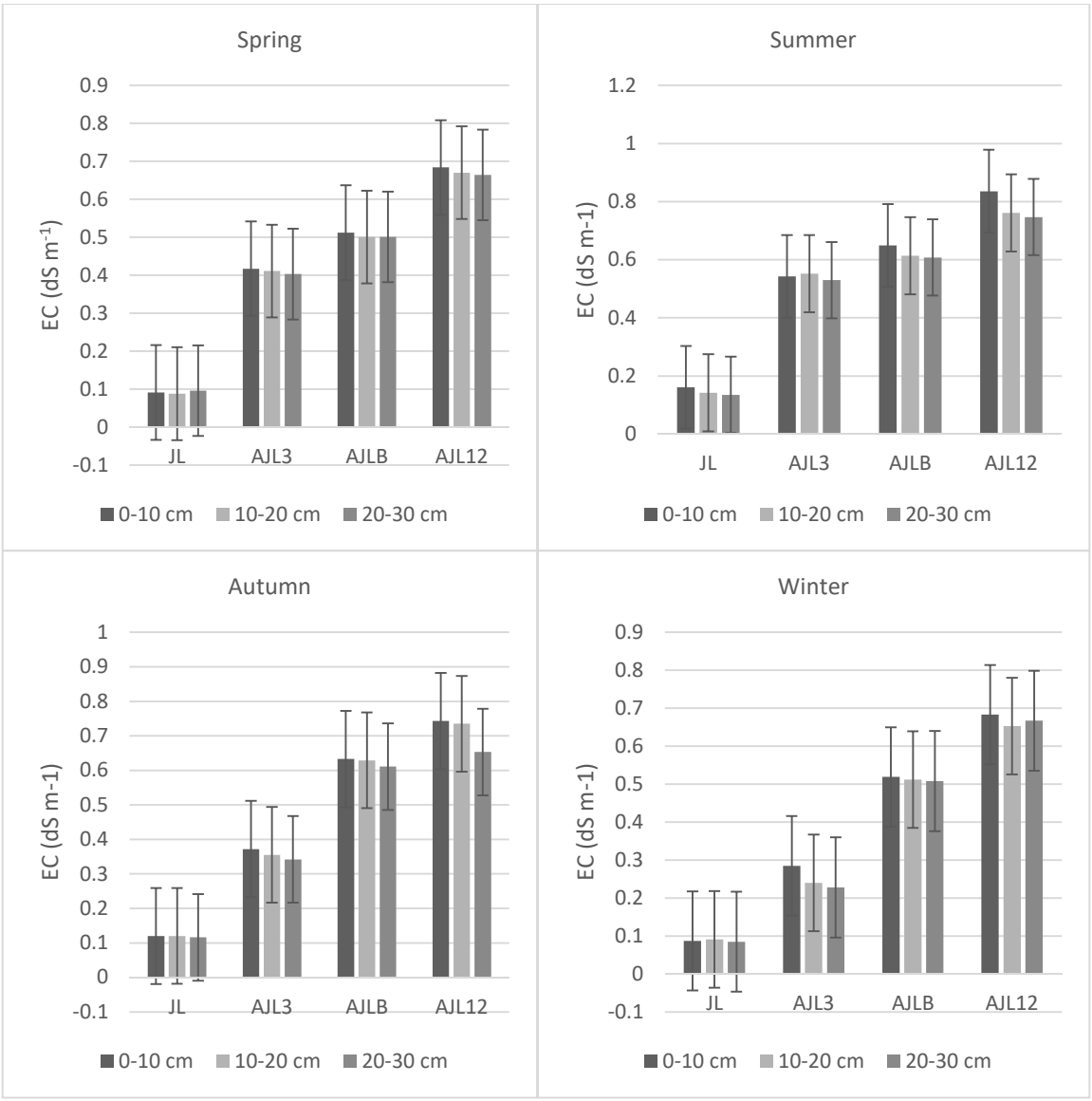

Fig. 4.2: Seasonal variation of EC across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

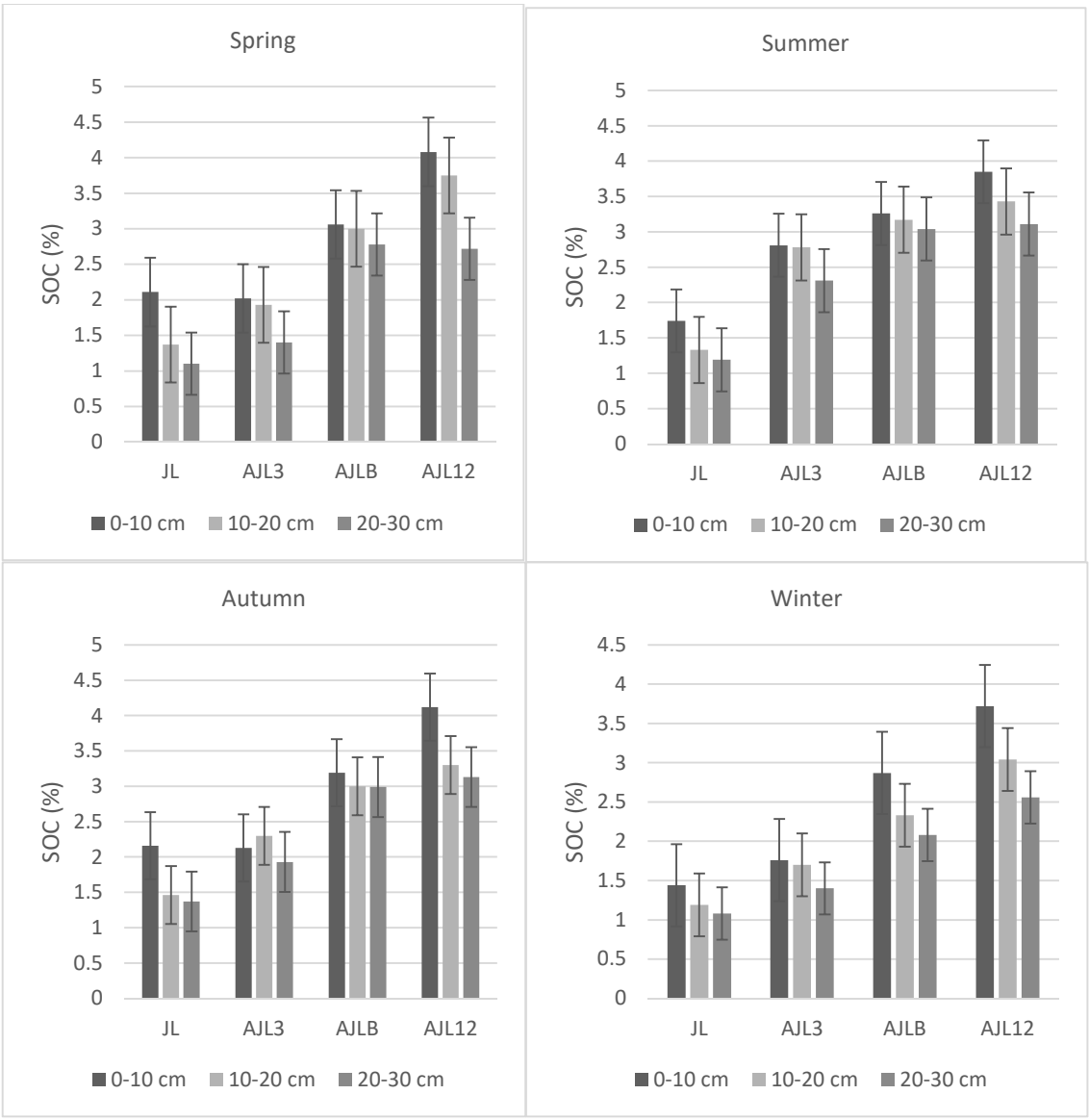

Fig. 4.3: Seasonal variation of SOC across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

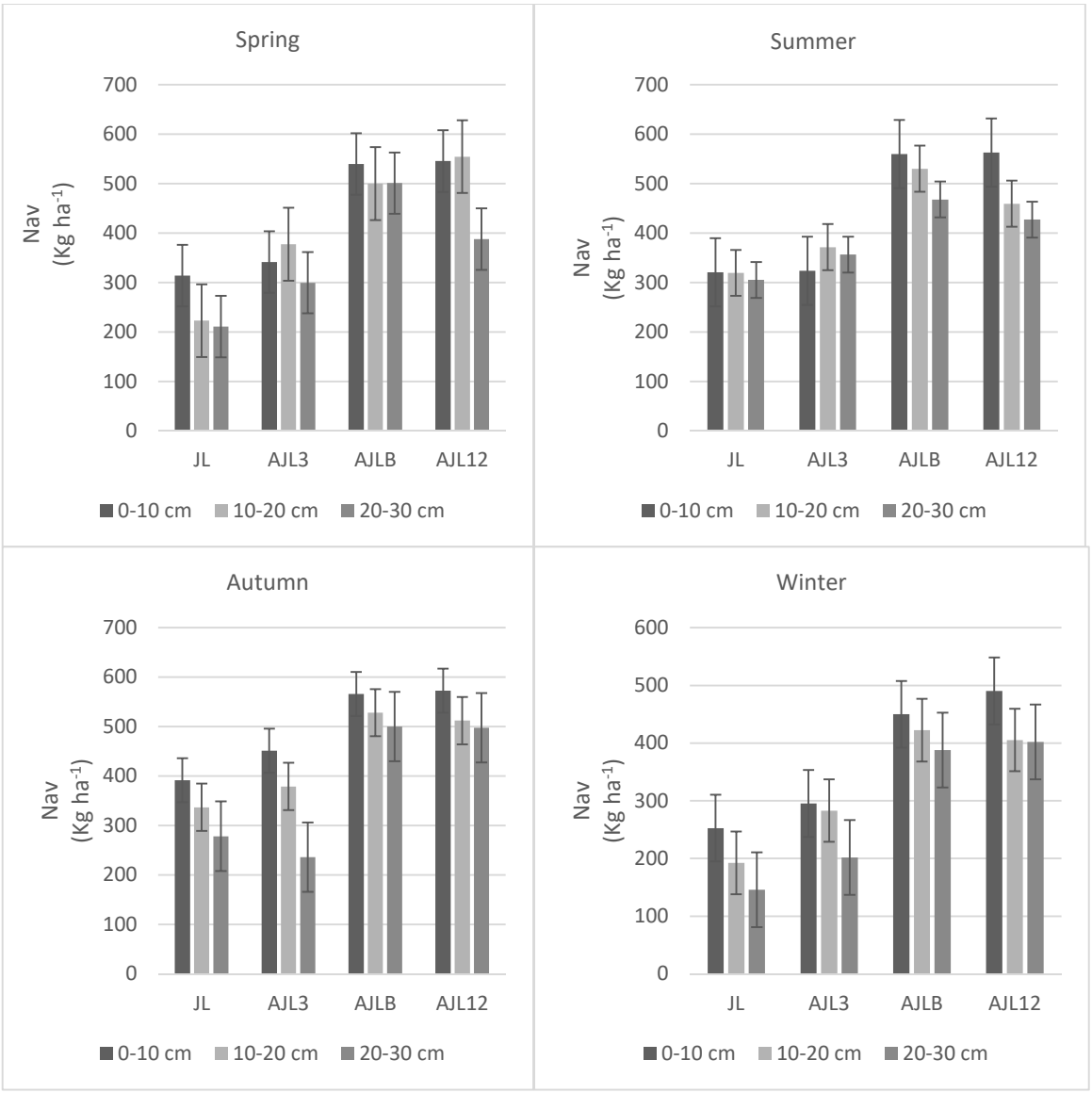

Fig. 4.4: Seasonal variation of N_{av} across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

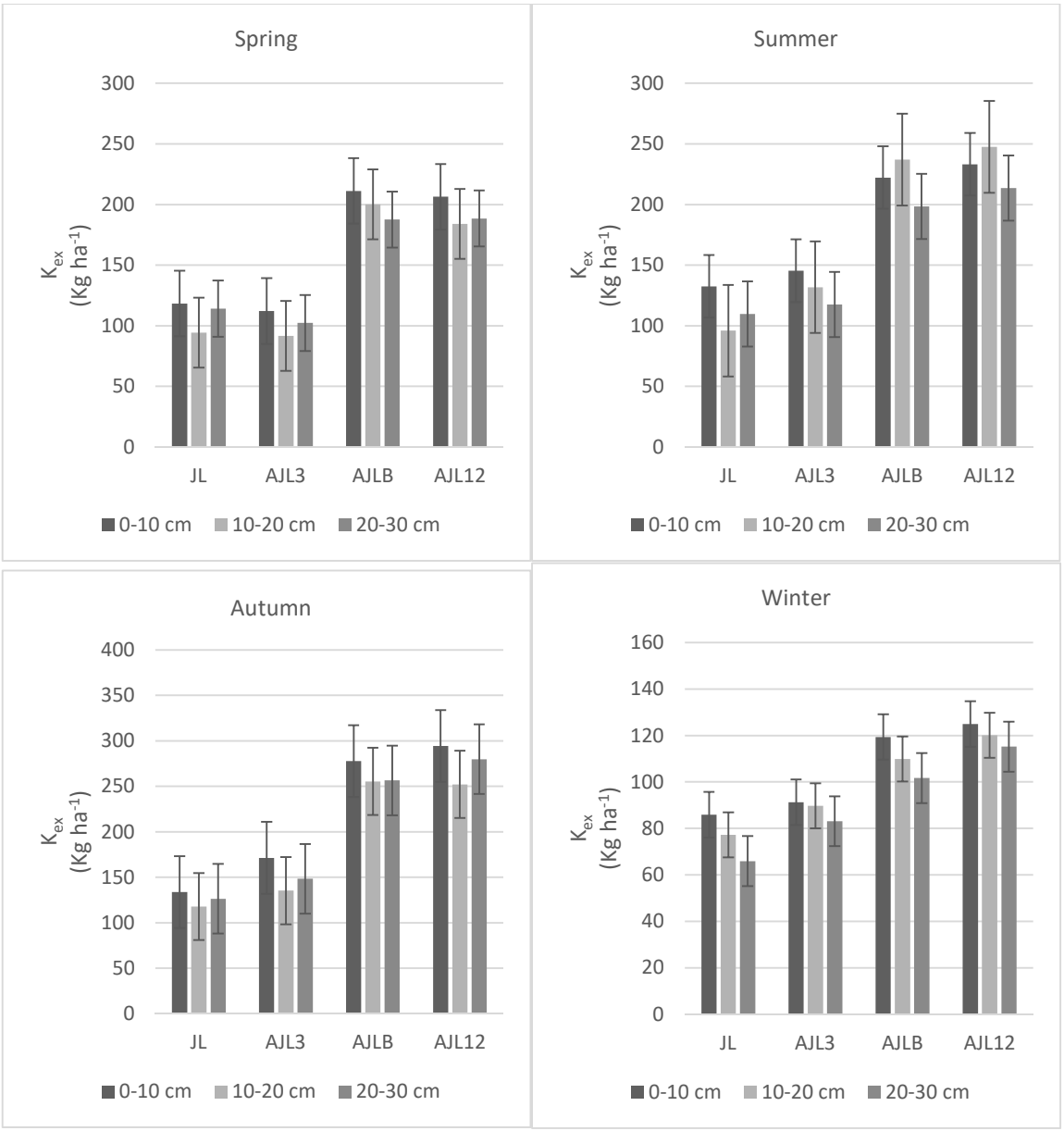

Fig. 4.5: Seasonal variation of K_{ex} across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

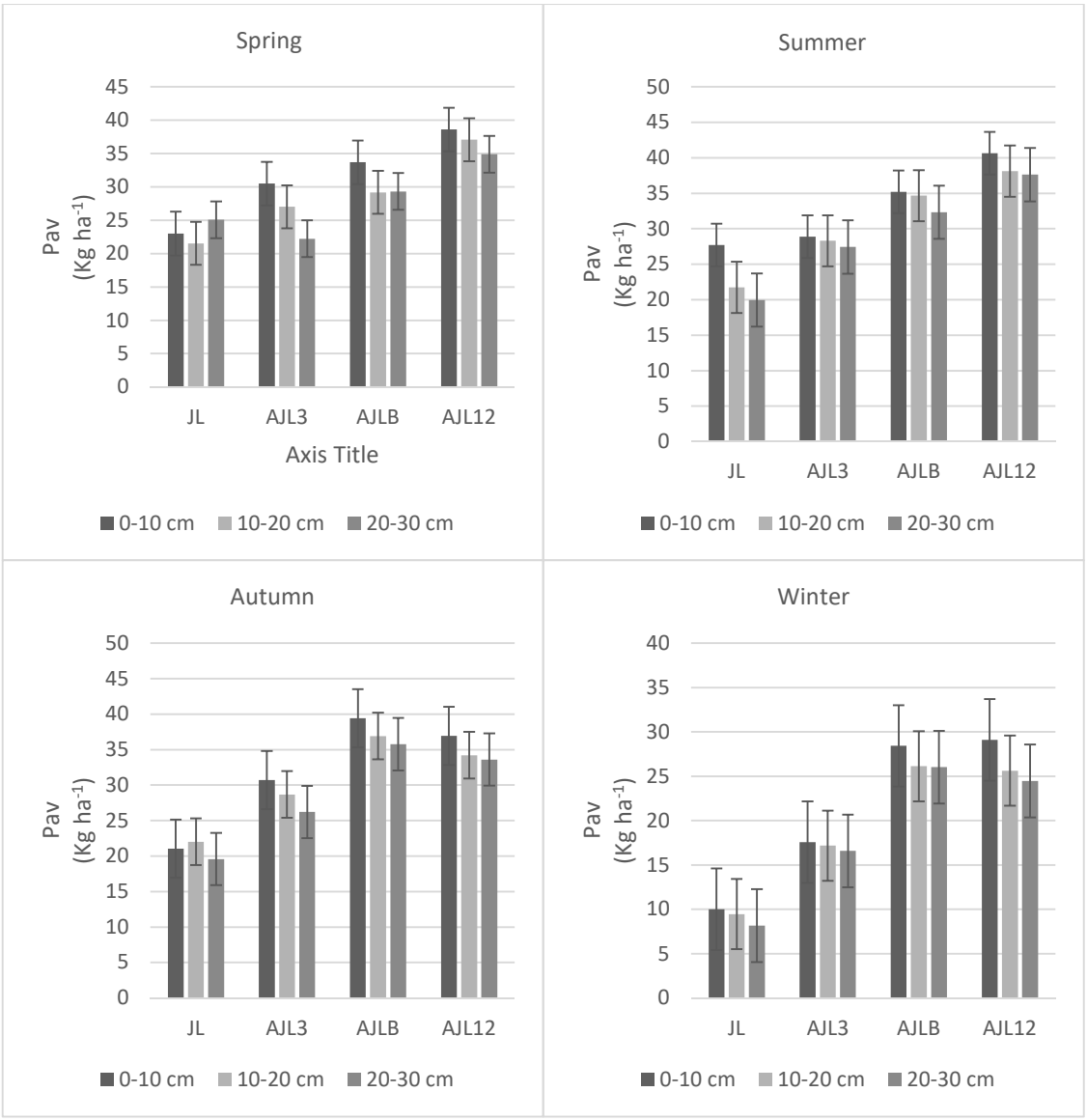

Fig. 4.6: Seasonal variation of P_{av} across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

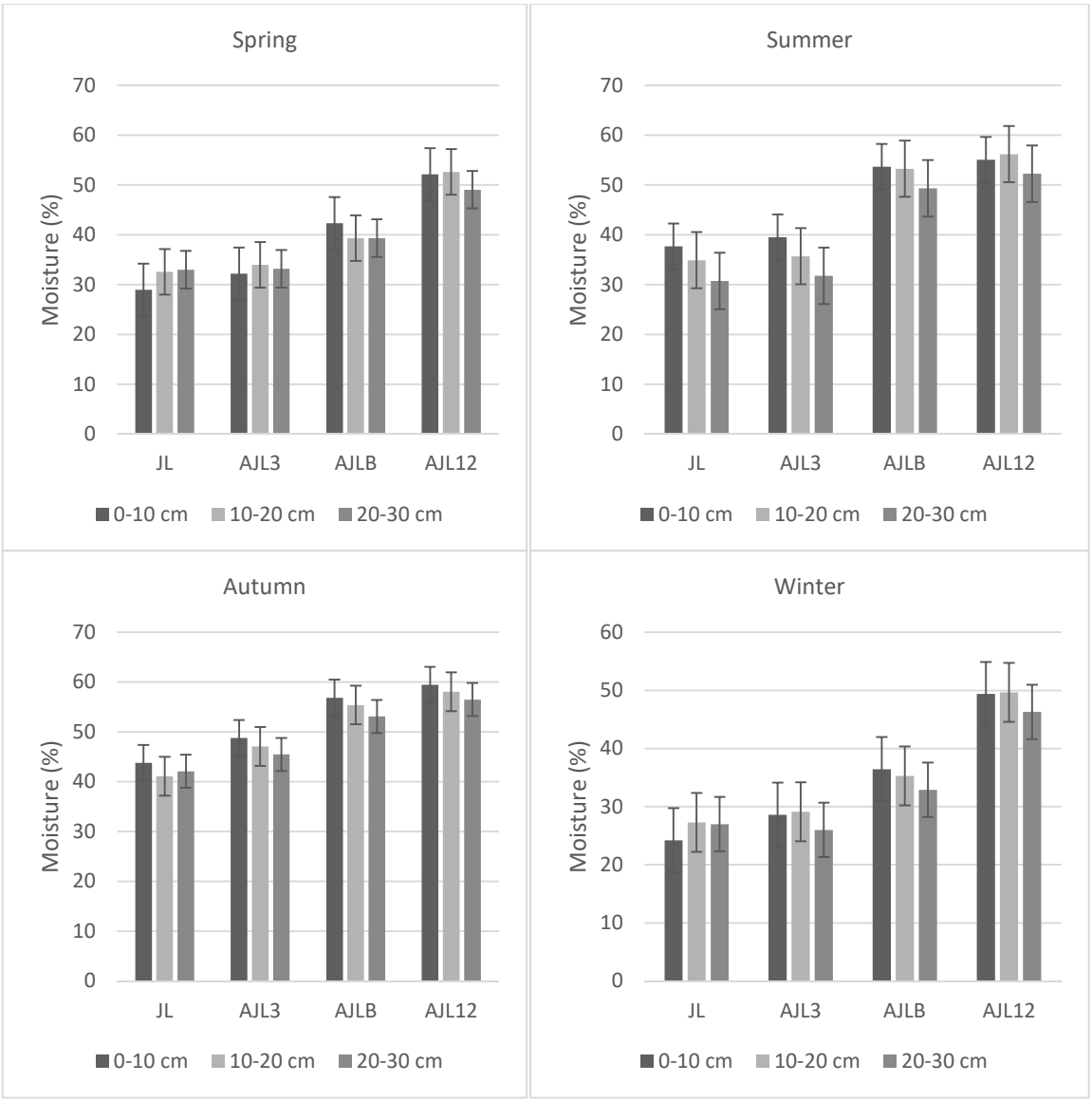

Fig. 4.7: Seasonal variation of Moisture across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

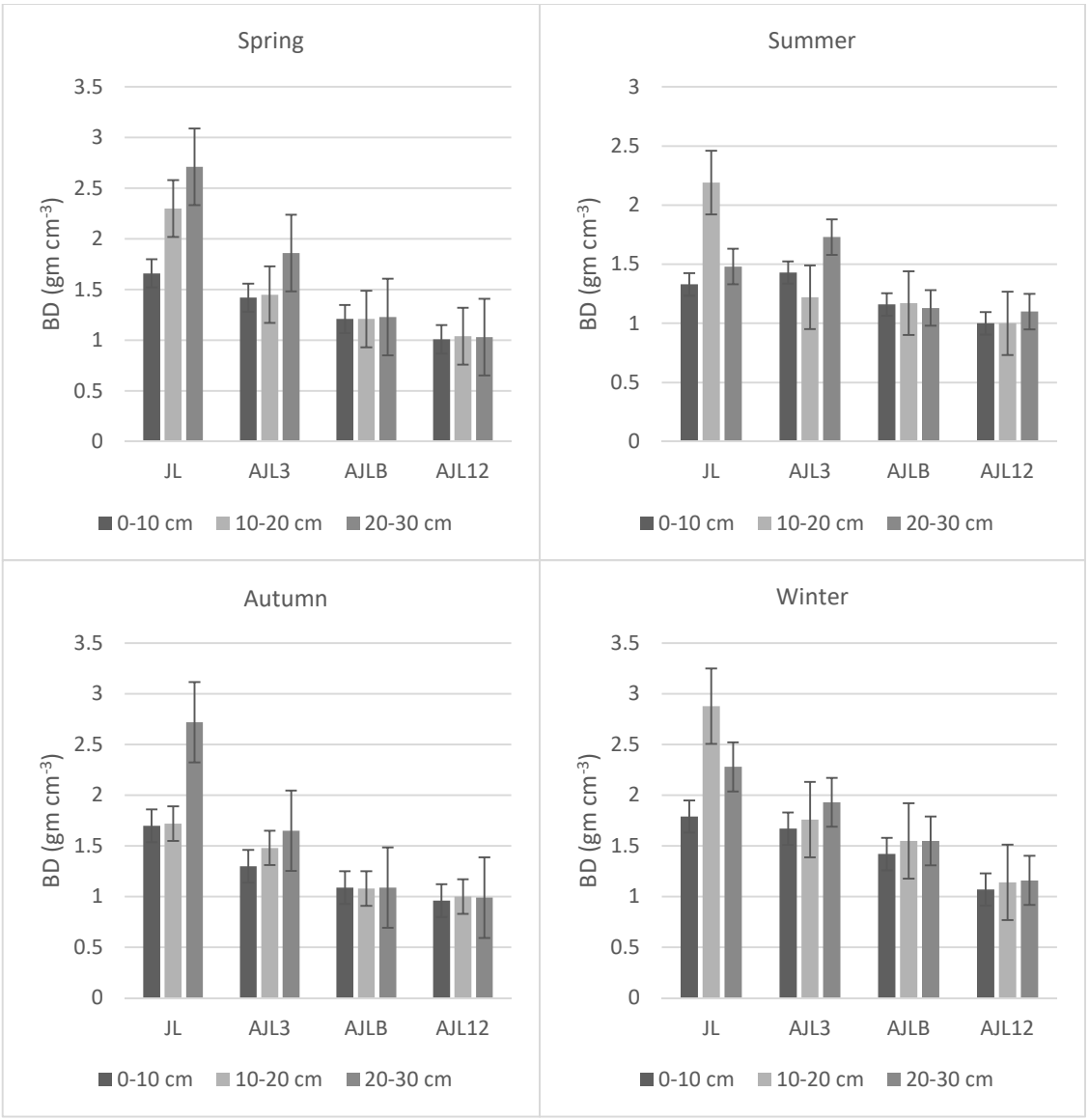

Fig. 4.8: Seasonal variation of BD across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

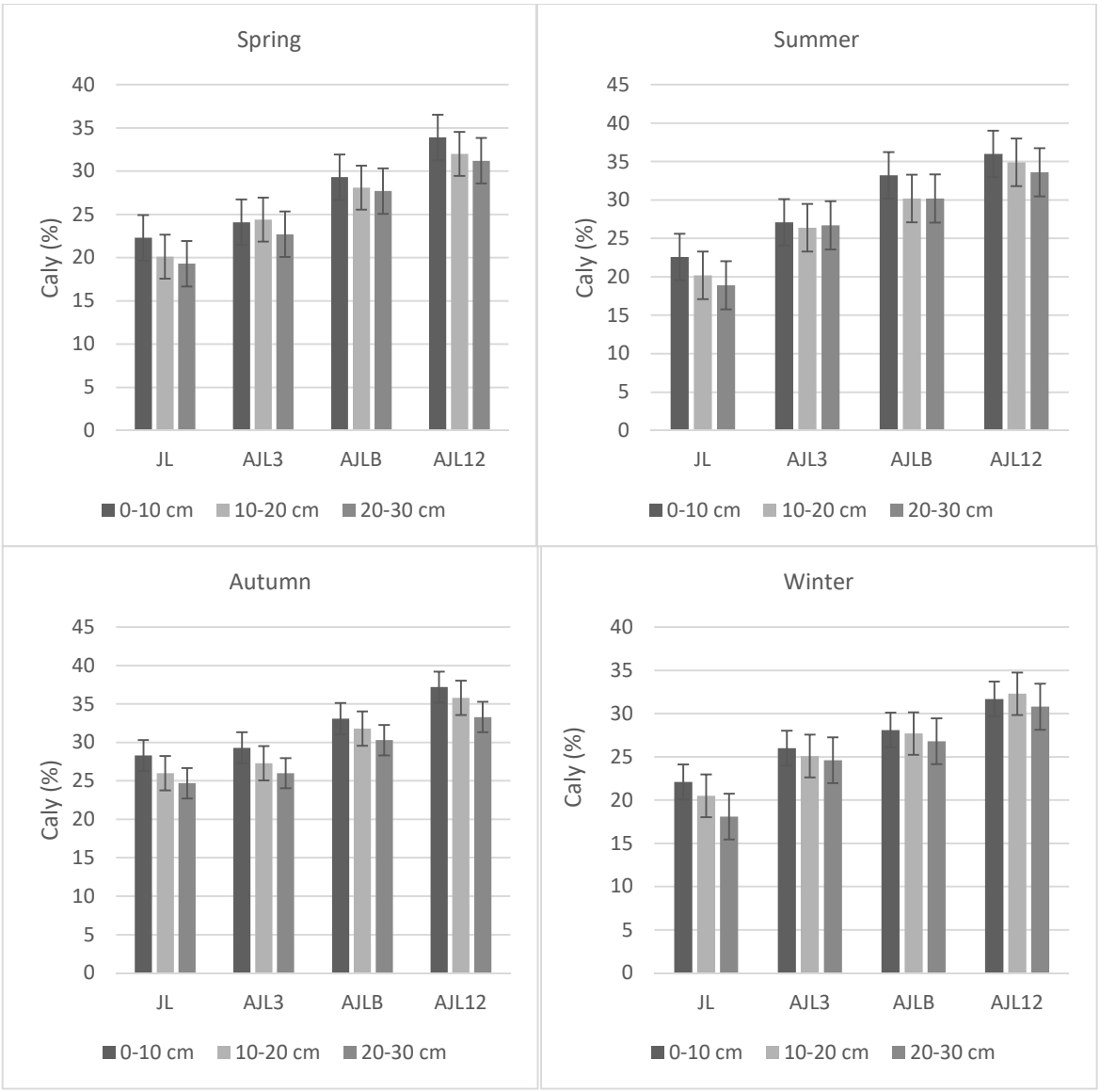

Fig. 4.9: Seasonal variation of Clay across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

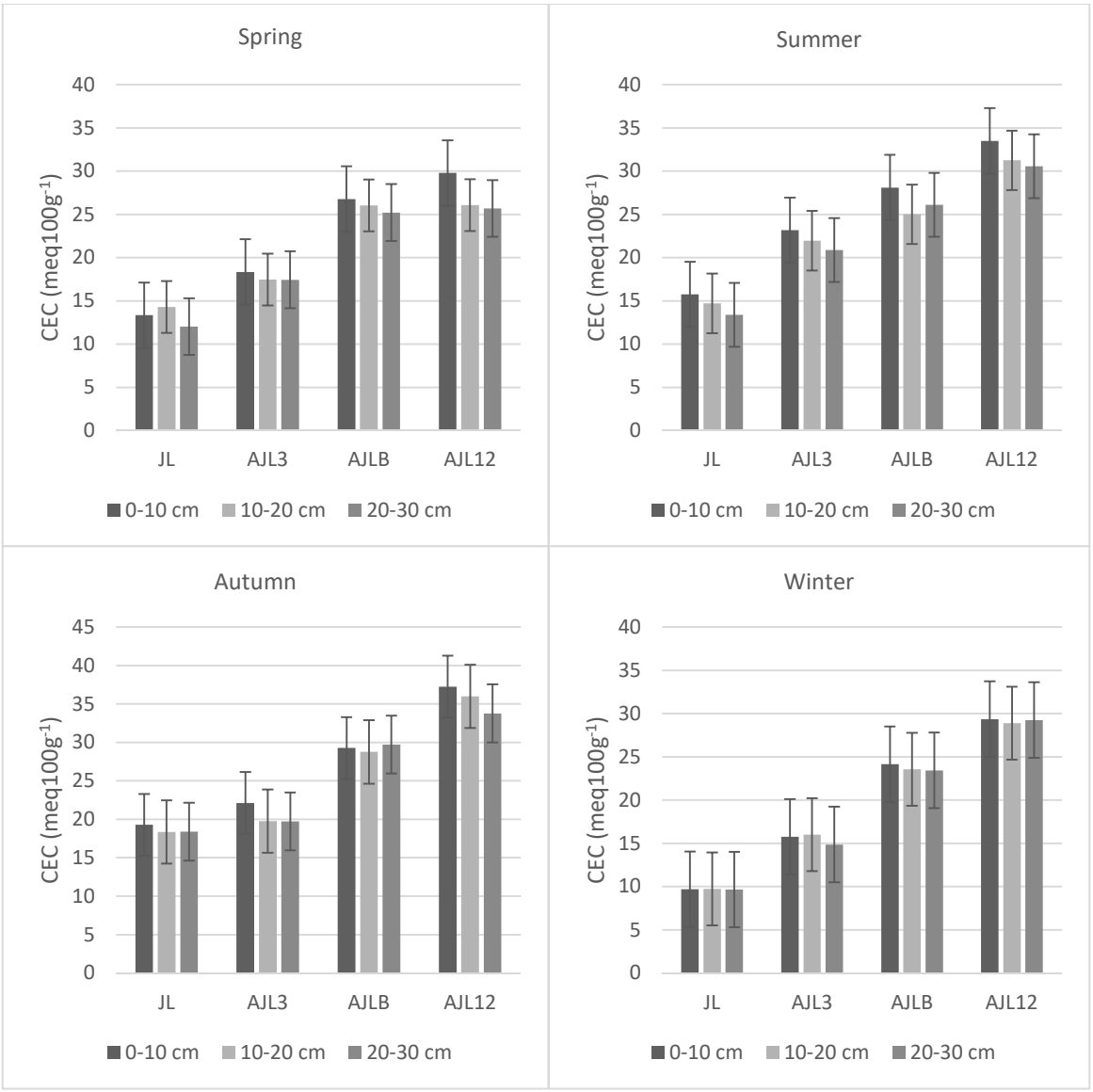

Fig. 4.10: Seasonal variation of CEC across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

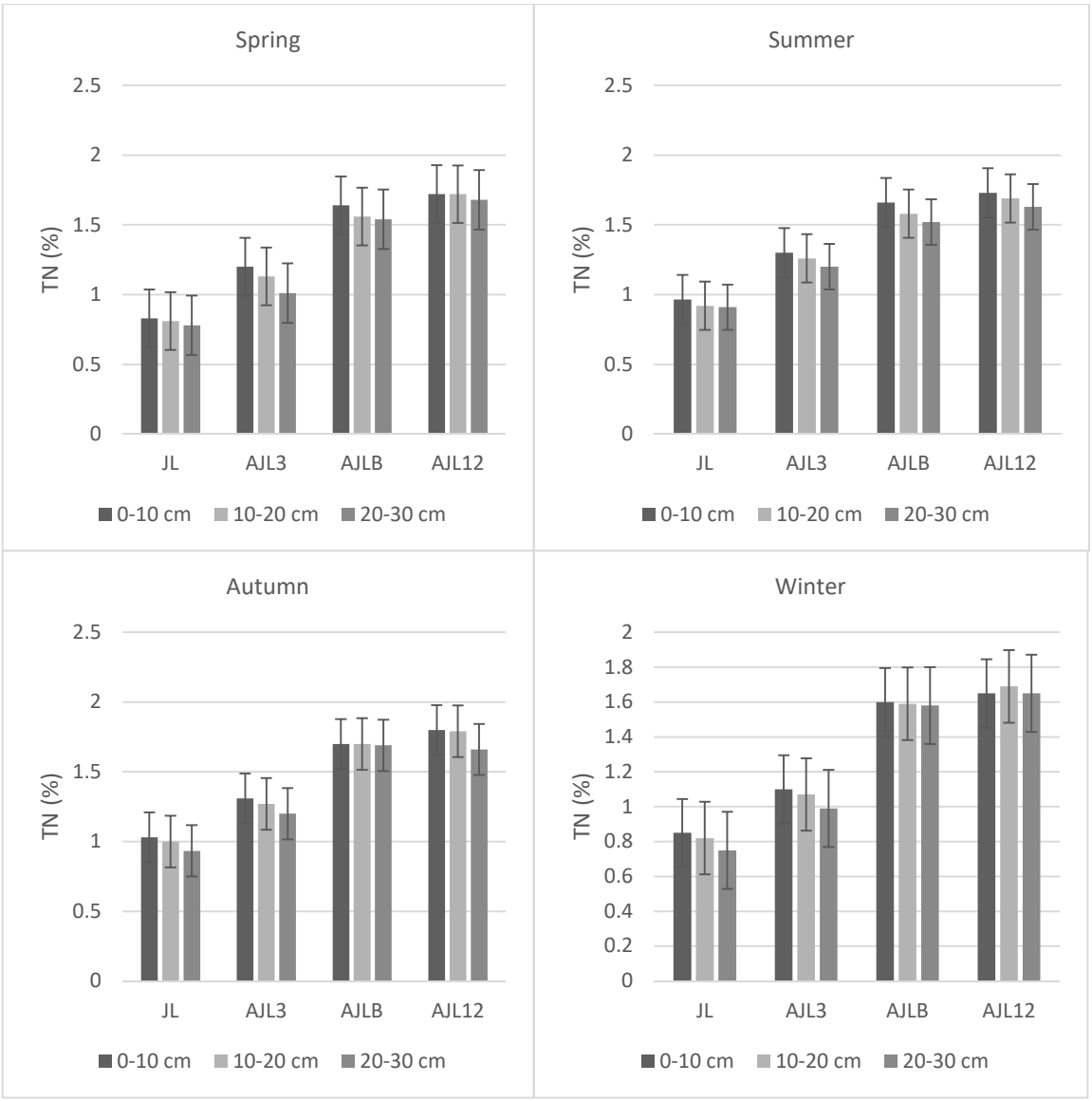

Fig. 4.11: Seasonal variation of TN across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

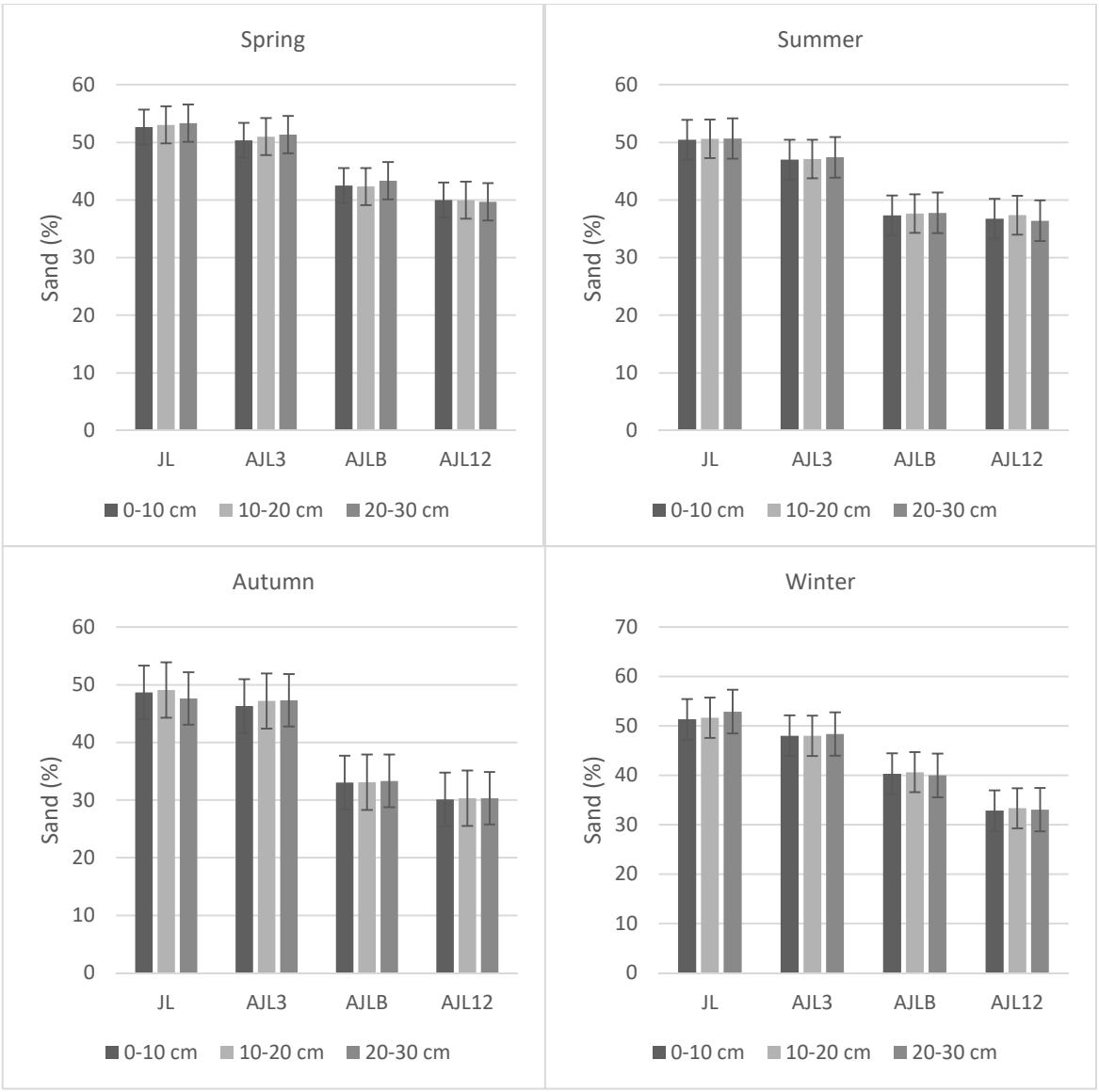

Fig. 4.12: Seasonal variation of Sand across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

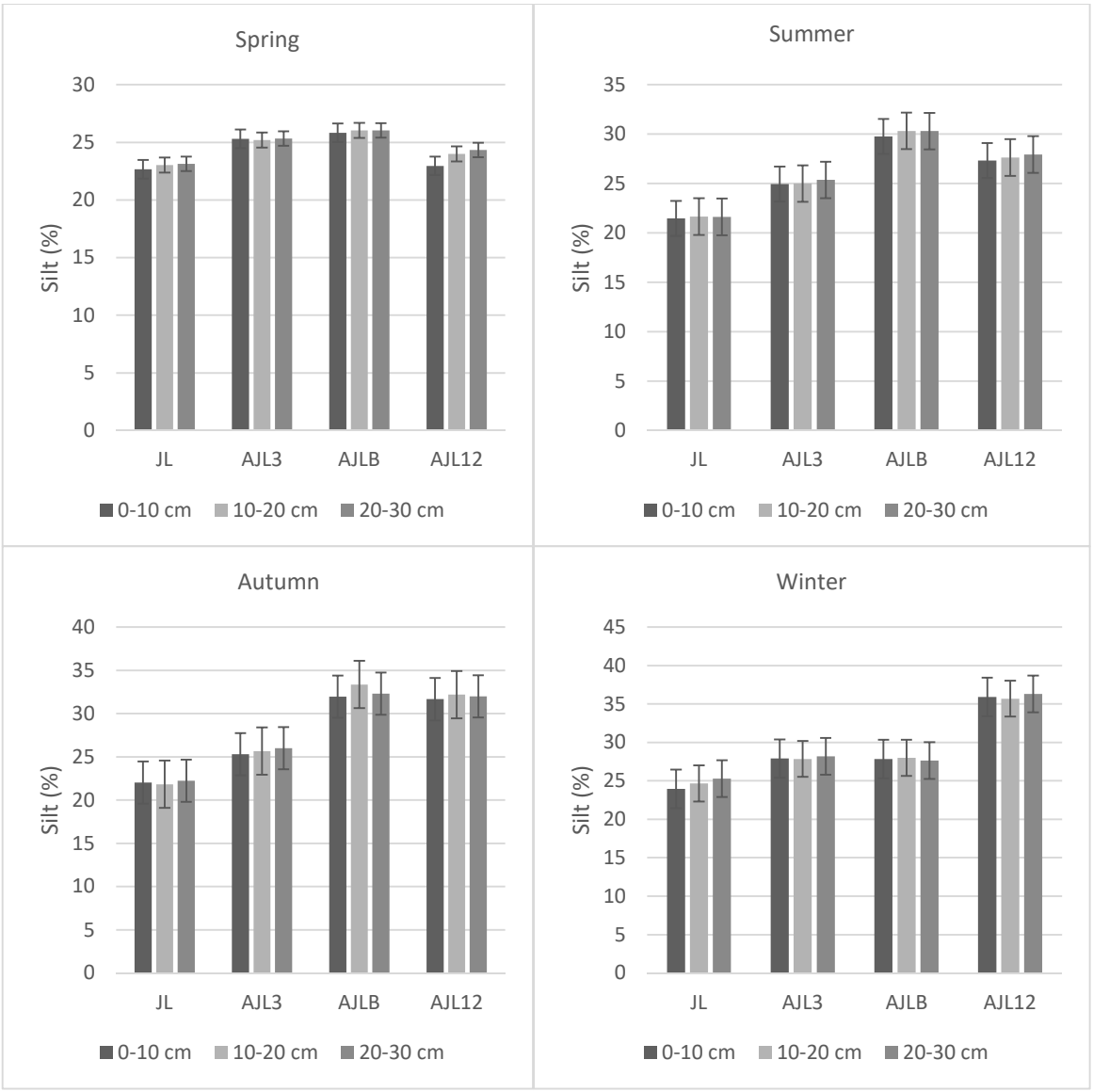

Fig. 4.13: Seasonal variation of Silt across soil depths (0-10cm, 10-20cm, 20-30cm) at sites JL, AJL3, AJLB and AJL12

3.2.2 Comparison of soil layer between the sites

The result of the comparison of soil layer between the sites (0-10 cm, 10-20cm, 20-30 cm) among the different sites is presented in **Table 4.**

Soil at 0-10 cm layer depth: AJL12 possessed lowest pH value (4.88), while JL depicted higher pH values (5.60). Similar observation was mode for EC, with lower values at JL and higher values at AJL12, respectively. In contrast, SOC values were higher at AJL12 (3.94%) and lower at JL (1.86%). A similar observation was made for clay content, CEC, TN, Silt content, $N_{av,}$ K_{ex} and P_{av}, with their value increasing significantly over JL<AJL3<AJLB<AJL12, respectively. There was no report of significant variation in moisture content amongst all the sites. BD and Sand content decreased from sites in the order JL>AJL3>AJLB>AJL12, respectively.

Soil at 10-20 cm layer depth: JL possessed greater values of pH value (5.60) while lower values were reported at AJLB (5.04) and AJL12 (5.00), respectively. Similarity an increase in EC and SOC values were observed with introduction of longer fallow periods. A similar trend was observed for clay content, CEC, TN, Silt content, moisture, $N_{av,}$ K_{ex} and P_{av}, with their value increasing significantly over JL<AJL3<AJLB<AJL12, respectively. JL depicted higher BD and sand content. In contrast significantly lower values of BD and sand content was observed with implementation of fallow.

Soil at 20-30 cm layer depth: A similar trend was observed at the 20-30 cm with significantly lower soil pH value were reported at AJL12 (4.89) with higher pH values at JL. A similar trend was observed for EC, SOC, $N_{av,}$ K_{ex} and $P_{av,}$ Moisture, clay, CEC, TN, and silt with their value increasing significantly over JL<AJL3<AJLB<AJL12, respectively. BD and Sand content decreased from sites JL>AJL3>AJLB>AJL12, respectively.

Table 4: Depth-wise comparison of the mean values of soil parameters between the different study sites

Soil depth	Sites	pH	EC (dS m^{-1})	SOC (%)	N_{av} (Kg ha^{-1})	K_{ex} (Kg ha^{-1})	P_{av} (Kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq100g^{-1})	Total Nitrogen (%)	Sand (%)	Silt (%)
0-10 cm	JL	5.60^{a}	0.0942^{a}	1.86^{a}	320.71^{a}	117.51^{a}	20.44^{a}	33.67^{a}	1.62^{c}	23.82^{a}	14.50^{a}	0.92^{a}	50.79^{c}	22.53^{a}
	AJL3	5.22^{ab}	0.404^{b}	2.18^{b}	353.08^{a}	129.31^{ab}	26.92^{ab}	37.27^{a}	1.45^{c}	26.6^{b}	19.85^{a}	1.23^{b}	47.85^{b}	25.86^{b}
	AJLB	5.09^{b}	0.578^{c}	3.09^{c}	527.90^{b}	184.26^{bc}	32.17^{bc}	47.33^{a}	1.22^{b}	30.85^{c}	27.14^{ab}	1.65^{c}	38.30^{a}	28.85^{c}
	AJL12	4.88^{b}	0.736^{d}	3.94^{d}	542.99^{b}	214.75^{c}	36.32^{c}	46.52^{a}	1.01^{a}	34.70^{c}	44.65^{b}	1.72^{d}	35.69^{a}	29.71^{c}
10-20 cm	JL	5.60^{a}	0.110^{a}	1.33^{a}	267.99^{a}	96.31^{a}	18.69^{a}	33.97^{a}	2.27^{b}	21.70^{a}	14.27^{a}	0.88^{a}	51.10^{b}	22.80^{a}
	AJL3	5.22^{ab}	0.389^{b}	2.17^{b}	352.83^{a}	112.16^{b}	25.41^{ab}	36.47^{a}	1.47^{b}	25.80^{b}	18.79^{ab}	1.18^{b}	48.32^{b}	25.93^{b}
	AJLB	5.04^{b}	0.556^{c}	2.72^{c}	491.36^{b}	197.06^{b}	31.71^{bc}	45.82^{b}	1.25^{a}	29.45^{c}	28.84^{c}	1.61^{c}	38.43^{a}	29.43^{c}
	AJL12	5.00^{b}	0.704^{d}	3.38^{d}	482.88^{b}	200.99^{b}	33.76^{c}	54.14^{b}	1.04^{a}	33.75^{c}	29.90^{c}	1.74^{d}	36.42^{a}	29.88^{c}
20-30 cm	JL	5.57^{a}	0.108^{a}	1.18^{a}	235.16^{a}	104.07^{a}	18.18^{a}	33.20^{a}	2.29^{c}	20.25^{a}	13.36^{a}	0.84^{a}	50.91^{b}	23.07^{a}
	AJL3	5.22^{ab}	0.375^{b}	1.76^{b}	273.60^{a}	112.83^{a}	23.11^{ab}	34.12^{a}	1.79^{b}	25.00^{b}	18.22^{a}	1.10^{b}	48.60^{b}	26.22^{b}
	AJLB	5.09^{b}	0.540^{c}	2.36^{c}	464.363^{b}	170.28^{ab}	29.27^{bc}	43.67^{ab}	1.25^{a}	28.75^{c}	26.11^{b}	1.58^{c}	38.6^{a}	29.07^{c}
	AJL12	4.89^{b}	0.682^{d}	2.88^{d}	428.77^{b}	199.30^{c}	32.65^{c}	51.03^{b}	1.07^{a}	32.25^{c}	28.01^{b}	1.65^{c}	36.1^{a}	30.14^{c}

Values are expressed as mean. Values in the same column with different superscripts in their respective soil depth are significantly different at 5% level by Duncan's multiple range test (p<0.05).

3.2.3 Soil quality index generation and comparison:

Comparison of SQI of the different study sites are presented in Fig. 5.1 and Fig. 5.2. The result of the Principal Component Analysis (PCA) accounted for a total variance of 79.97% at JL, 80.26% at AJL3, 77.14% at AJLB and 72.47% at AJL12, respectively (Table 5). From the results it is observed that at site JL, three components i.e., PC-1 (CEC), PC-2 (BD) and PC-3 (clay) were isolated as the MDS. Similarly at site AJL3, three Principal components were isolated i.e., PC-1 (SOC), PC-2 (Moisture) and PC-3 (pH) respectively. Two Principal components were isolated at AJLB with P_{av} and SOC retained at PC-1 and PC-2, respectively. Finally, at AJL12, two Principal components, i.e., Moisture for PC-1 and SOC for PC-2 were retained. Next, the indicators from the MDS were scored to obtain the SQI of the four sites. The additive index (SQI_a) was in the order JL<AJL3<AJLB<AJL12. The values were reported as 0.79 (0-10 cm), 0.78 (10-20 cm) and 0.72 (20-30 cm) at JL; 0.81 (0-10 cm), 0.82 (10-20 cm) and 0.79 (20-30 cm) at AJL3; 0.94(0-10 cm), 0.92 (10-20 cm) and 0.91 (20-30 cm) at AJLB and finally, 0.92 (0-10 cm), 0.91(10-20 cm) and 0.89 (20-30 cm) at AJL12. For the weighted index, SQI_w it was in the order JL<AJL3<AJLB<AJL12. The values were reported as 0.68 (0-10 cm), 0.67 (10-20 cm) and 0.63 (20-30 cm) at JL; 0.73 (0-10 cm), 0.73 (10-20 cm) and 0.71 (20-30 cm) at AJL3; 0.79 (0-10 cm), 0.78 (10-20 cm) and 0.76(20-30 cm) at AJLB; 0.82 (0-10 cm), 0.81 (10-20 cm) and 0.79(20-30 cm) at AJL12, respectively.

Table 5: Principal Component Analysis (PCA) result with factor loadings of the different soil parameters from the study sites

Site	JL			AJL3			AJLB		AJL12	
Principal Component	**PC-1**	**PC-2**	**PC-3**	**PC-1**	**PC-2**	**PC-3**	**PC-1**	**PC-2**	**PC-1**	**PC-2**
Eigen value	5.63	1.33	1.02	5.82	1.16	1.03	6.12	1.61	5.59	1.165
%Variance	56.37	13.34	10.26	58.278	11.635	10.357	61.23	16.14	55.91	16.55
%Cumulative frequency	56.37	69.71	79.97	58.278	69.912	80.269	61.23	77.14	55.91	72.47
Factor loadings										
CEC	0.**852**	0.226	0.344	0.604	0.438	0.457	0.861	0.332	0.886	0.319
EC	0.845	0.134	0.007	0.799	-0.038	0.463	0.733	0.336	0.402	0.565
Moisture	0.782	0.123	0.408	0.249	**0.854**	0.198	0.676	0.677	**0.896**	0.301
P_{av}	0.737	0.484	-0.112	0.731	0.498	0.233	**0.995**	0.886	0.393	0.736
K_{ex}	0.672	0.602	0.167	0.362	0.804	0.279	0.628	0.626	0.871	0.360
N_{av}	0.595	0.553	0.394	0.775	0.349	-0.046	0.571	0.374	0.296	0.769
BD	-0.365	**-0.857**	-0.035	-0.814	-0.366	0.023	-0.669	-0.383	-0.630	-0.570
SOC	0.048	0.845	0.400	**0.891**	0.300	0.092	0.231	**0.963**	-0.237	**0.899**
Clay	-0.003	0.152	**0.888**	0.208	0.763	-0.095	0.616	0.390	0.507	0.491
pH	.0326	0.144	0.667	0.063	0.110	**0.905**	0.608	0.774	0.791	-0.116

Bold indicates the highest loaded factor in each principal component

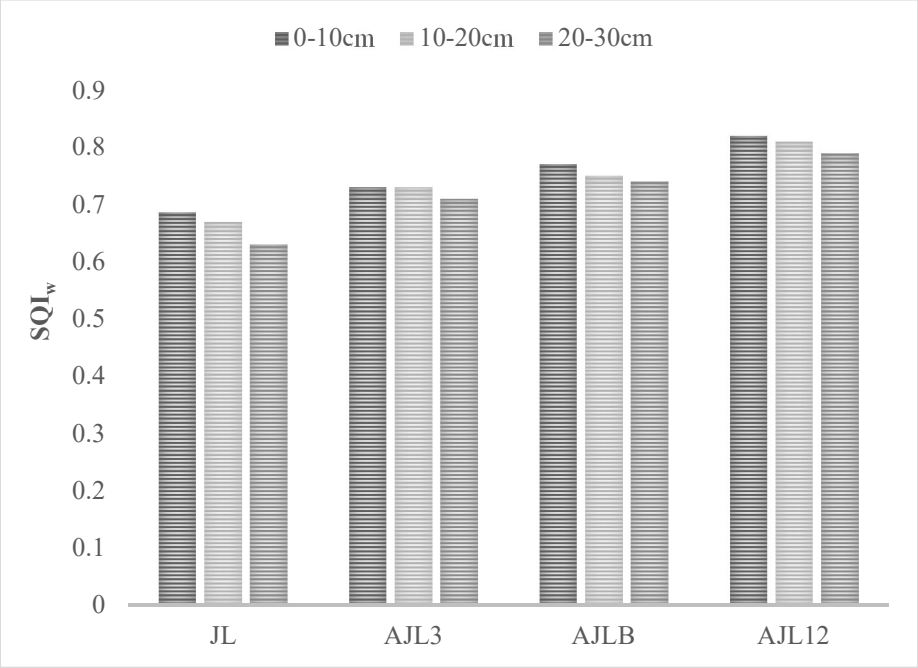

Fig. 5.1: Weighted index SQI_w generated from JL, AJL3, AJLB and AJL12

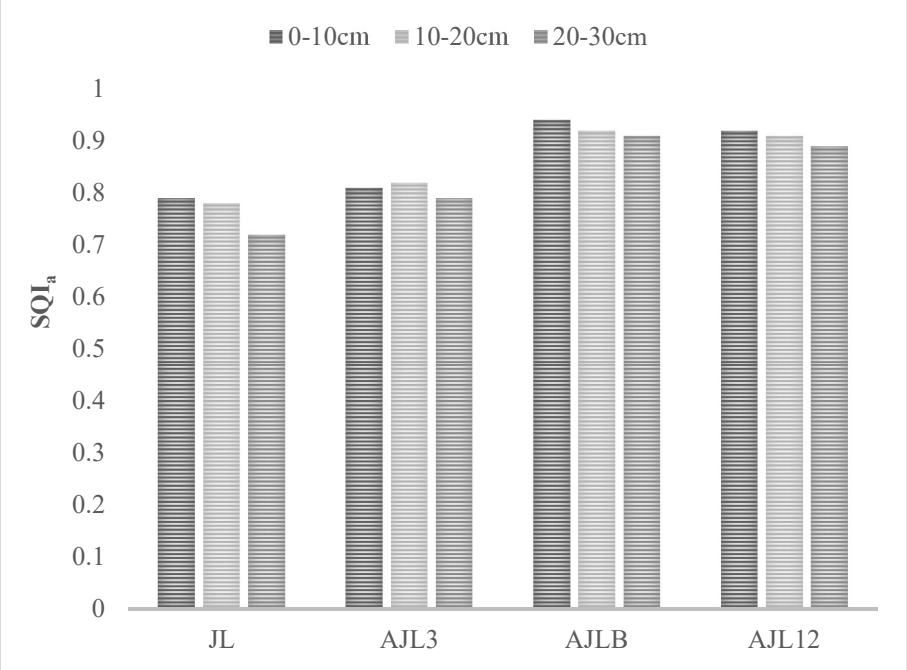

Fig. 5.2: Additive index SQI_a generated from JL, AJL3, AJLB and AJL12

3.3 DISCUSSION

3.3.1 Seasonal variation in soil properties

The onset of heavy rainfall during summer and autumn increases the moisture content in the soil. In contrast, with winter receiving little to no rainfall, soil moisture decreases. Therefore, soil moisture follows the expected seasonal trends, i.e., winter<spring<summer<autumn. The variation in the soil moisture content significantly alter the soil texture (clay, silt and sand). Tesfahunegn and Gebru (2020) similarly report on the increased clay content during the monsoon period due to the increased precipitation. This elevated moisture content also significantly reduces the soil BD levels. Variation in rainfall patterns alters the soil texture which affects the deposition–transportation process. This results in higher clay content during the warmer period, which is accompanied by rainfall, in comparison to the colder periods which receive lower precipitation. Higher values of soil pH (less acidic) are observed during autumn, lower values of pH are observed during winter. During winter, the decreased pH value may be attributed to a combination of organic acid released via decomposition and decreased moisture content. With the onset of the rainy season, there is a restoration of moisture which increases the soil pH value. A similar report on the relationship between moisture and pH has been established by Baruah *et al.* (2018) on the soils of Assam, India. They reported a decreased pH value of 4.36 during winter and an increased pH value of 4.73 during the monsoon (rainy) season, respectively. Guojo *et al.* (2020) similarly report that an increase in temperature (0.5–2 ^{0}C) significantly increased pH value (0.42–0.67). We record a similar trend, wherein pH value increases as temperature rises during the warmer season. Higher EC values were recorded during the rainy season at all the different sites. This may be attributed to a surge in rainfall which increases the leaching of salts present from the rhizosphere network into the soil (Tesfahunegn and Gebru, 2020). We recorded higher SOC values during the warmer (summer and autumn) periods in the present study. This may likely be attributed to higher carbon input from the decomposition of litter during the warmer season, which eventually increases SOC levels (Zhao *et al*., 2009). The elevated SOC content during the warmer season also exhibits a positive relationship with CEC. Thus, the increased levels of SOC during the summer and autumn season additionally lead to higher negative colloid that increases CEC values in the soil (Dutta *et al*., 2011; Tesfahunegn and Gebru, 2020). Similarly, the levels of TN, $N_{av,}$ P_{av} and K_{ex} increased with the onset of summer and autumn.

The present findings agree with Mahajan *et al*. (2021), who similarly report on higher litter input and organic matter during the warmer period. In contrast, abiotic stress, such as the reduced temperature and moisture, limits the mineralization process during the colder seasons (Moebius *et al*., 2007).

3.3.2 Comparison in soil parameter between sites

We observed that soil quality (depthwise) followed the order 0–10 cm>10–20 cm>20–30 cm, for all the study sites. pH values amongst the site were higher at JL. This increased value may be because of two factors: the practice of adding salt to control weeds and the periodic burning of the site vegetation (Temjen *et al*., 2022). The introduction of the fallow period leads to a decrease in pH values at the study site. This is attributed to the increased input of organic matter from both above and below ground biomass at sites AJL3, AJLB and AJL12, respectively. Brady and Weil (2002) similarly report that organic matter in the form of litter and compost reduces soil pH. Furthermore, soil pH was reported to be lower in the upper soil depth (0–10 cm). The higher rate of decomposition in the upper humus-rich layer may be one reason for the increased pH values in this zone (0–10 cm). EC is a critical parameter as its abundance in soil may relatively affect the plant growth and hence its optimum presence is conducive for a favourable soil health (Semy *et al*., 2022). In the present study, EC values increased with introduction of fallow. A similar observation was reported by Tellen and Yerima (2018) in North West region of Cameroon. The worker also reported that utilization of chemical inputs did not significantly alter the EC values at cultivated lands, highlighting the need for organic fertigation. Increased EC values in the upper soil region may be attributed to the elevated levels of SOC. The higher SOC allows for increased water retention and higher conductivity in the soil (Hawkins *et al.*, 2017). Consequently, in the present study, the lowest SOC was reported at JL. Continuous cropping and soil tillage practices break down and remove organic residues from the soil, depleting SOC (Chandel and Hadda, 2018). Meanwhile, an increase in the fallow period allows for additional litter decomposition and turnover rate, improving SOC values. SOC has been reported to aid the structural stability of soil by increasing its CEC and moisture content (Leeper and Uren, 1993). The higher SOC in the upper soil layer (0–10 cm) may also be attributed to active litter decomposition in this zone (0–10 cm). Therefore, we observe that the depletion of SOC levels under JL, due to intensive continued cropping, also reduces the CEC values of soil. Yimer *et al.* (2008) report on the positive relationship between SOC and

CEC. The present study reports a similar trend wherein JL possessed the lowest SOC and CEC values, while the introduction of fallow significantly increased the SOC and CEC content at AJL3, AJLB and AJL12. Significantly elevated TN, N_{av}, P_{av} and K_{ex} values were also reported with the introduction of fallow. The increased addition of organic matter through litter-fall and greater root biomass may be one factor for the higher macronutrients in the fallow sites (Neha *et al*., 2020; Dhaliwal and Dhaliwal, 2019). A significant reduction in BD levels with introduction of fallow was also reported. The present findings are supported by Zolfaghari and Hajabbasi (2008), who similarly remarked on the decreased BD content at forest sites as compared to Jhum lands. The increased organic matter and litter decreased the soil compaction in the fallow sites, leading to decreased BD values at AJL3, AJLB and AJL12 (Chauhan *et al*., 2019). The comparison of the four sites depict that the absence and increased cultivation cycle depicts increased soil compaction, reduced nutrient levels and moisture content at JL. The introduction of fallow enhances soil nutrients, clay, and moisture and regulates the soil pH and BD values. Similar reports on the negative impacts of shifting cultivation by the ethnic inhabitants and the reduced fallow on the soils of the North-East region have been documented (Getachew *et al*., 2012; Javad *et al*., 2014; Mishra *et al*., 2021).

3.3.3 Effect on introduction of *B. tulda* in degraded Jhum land

In comparison of sites AJL3 and AJLB, although both sites are similar in terms of the fallow period, the introduction of the *B. tulda* in Jhum land significantly affected soil recovery. Significantly elevated EC, SOC, N, Moisture, clay, CEC, TN, reduced BD and changes in the soil texture were recorded (**Table 4**). A similar positive effect on their role in Jhum soils has been reported by Rao and Ramakrishnan (1988). They rapidly colonize disturbed lands and play a vital role in succession, owing to their high adaptability and nutrient conservation ability. The introduction of bamboos in degraded Jhum lands has been reported to increase the microbial diversity and create increased nutrient concentration owing to larger root area surface (Singh *et al*., 1989). The increased soil fertility is attributed to their rapid growth rate, high litter production and active nutrient cycling (Arunachalam and Arunachalam, 2002). Shiau *et al*. (2017) report that the different forms of N extracted from soils of bamboo plantations were 2-4 times greater as compared to sites with no bamboo plantations. Bamboo aids in the restoration of soil due to its high carbon sequestration capacity (Nath *et al*., 2015). The increased SOC also helps the microbes

maintain the N and C balance in the soil (Poeplau *et al*., 2017). This is especially useful in Jhum land, as the burning of vegetation releases a large amount of CO_2, which the bamboo can capture and sequester (INBAR, 2016). Besides their ecological role, it is also reported that the 3.1 million hectares of land occupied in the NE regions account for the nearly 66% of the total bamboo stock. With an estimated demand of 26.9 million tons, Salam (2013) reports that the global production of bamboo stands at 13.47 tons. This highlights that the current production rate is roughly meeting only half the bamboo requirement. He also highlights on the opportunities of bamboo market as good sectors for generation of employment especially in the rural areas. In Nagaland, Nagaland Bamboo Development Agency (NBDA), has proposed to regenerate 14,142 hectares of bamboos with species such as *Bambusa tulda, Bambusa balcooa,* ans *Bambusa pallida* as vaibale candiates (Anand, 2013). This has enabled for sequestration of approximately 0.17 tons of carbon dioxide annually. Such abilities highlight both the economic and ecological benefits of bamboo in the region (Ram *et al*., 2010; Konyak, 2022). Bamboo is an important component of livelihood component for the ingenious inhabitants of North-East India. The principal genera include *Arundinaria, Bambusa, Cephalostachyum, Chimonobambusa, Dendrocalamus, Dinochloa, Gigantochloa, Melocanna, Schizostachyum, Oxytenanthera, Phyllostachys, Pleioblastus, Sinarundinaria, Sinobambusa, Thamnocalamus* and *Thyrsostachys* (INBAR, 2016). Its utilization and wide uses as edibles, medicinal uses, construction material, and economic viability have established itself as the titular "green gold" owing to its importance among the communities of the region (Singh *et al*., 2010; Nath and Das, 2012).

3.3.4 Effects in soil characteristics due to *Musa* cultivars

The introduction of banana plantation on a large scale over a long period of time is reported to negatively affect soil by means of reducing the soil organic matter content, minerals and nutrients (Van Asten *et al.,* 2004). Peter Jr (2022), opined that farmer's management of soil practises significantly determine the rate soil degradation at banana plantations. The author reports that the implementation of no tillage and increased organic matter input decreases the negative impact of banana cultivation. It is observed that short term plantations of banana (below 5 years) coupled with organic supplements may benefit the soil ecosystem. The present study report a similar observation in the present study where in the introduction of *Musa* cultivars did not negatively alter the soil quality despite the

seasonal variations observed. Zhong *et al*. (2014) report on the negative effect of long term banana cultivation on the soil. They report on the significant increase in organic carbon, Total Nitrogen, available phosphorus, available potassium, and cations from years 1 to 5, which then decreased as the banana cultivation cycle increased (>15 years). Therefore in the present study, keeping in view the short term plantation nature of the cultivars, no significant negative effects on the soil by the cultivars is observed on the soil quality of the study site (**Table 4**). An additional positive influence of banana on soil is the increased carbon sequestration abilities in banana soils. The present study observed high SOC values ranging above 3% at sites AJLB and AJL12 in the study sites. This is higher than the SOC values reported by Semy *et al*. (2022) in Changki forest, Nagaland. The present findings is in agreement with Joris *et al*., (2013), who report on the increased carbon pool in banana plantation soils. This may be because of two factors. The first is that management of banana does not involve burning of the biomass. Second, the perennial and morphological features such as rapid growth may significantly aid in increasing the carbon sequestration capacity (Kamusingize *et al*., 2017). This is especially important in areas of North-East India, where shifting cultivation is the main source of agriculture. Such agricultural practise leads to loss of carbon from the soil during the removal of vegetation and the eventual burning. These depletion of carbon stocks from the agricultural ecosystem create significant carbon debt (Lal, 2011). The presence of rhizospheric fungi with the ability to solubilize insoluble ions in banana plantations have also been reported to increase the mineralization and ions uptake in the soil (Reena *et al*., 2013). Therefore, the sustainable utilization and short term management of *Musa* cultivars in Jhum fallow lands may not only significantly reduce its negative impact but may also obtain desirable effects on the soil.

3.3.5 MDS and Soil quality index selection

At the first site, i.e., JL, three MDS were retained from the TDS. The retained MDS were CEC, BD and clay. Therefore, increased BD levels and a reduction in the CEC and clay content is representative of site JL. In contrast with the implementation of fallow at AJL3, the retention of three MDS, i.e SOC, moisture and pH were recorded. Thus site AJL3 is characterised by the increased SOC and moisture content, while the pH level reduces. Similarly, at AJL12, two MDS, i.e., elevated SOC and moisture was observed. At AJLB, two MDS, i.e., SOC and P_{av} was reported. The introduction of bamboo at the fallow land

may lead to elevated organic input and increased carbon sequestration capacity, whereas the retention of P_{av} may highlight the increased mineralization at site AJLB.

In comparison and selection of SQI best suited for the region, the present study report we observe that SQI increases with an increase in the fallow period for both indexes. We further report that in both weighted and additive indexes, the SQI decreases with the increase in soil depth and vice versa. This trend was evident at all sites besides at AJLB. At AJLB, the study reports that the middle (10-20cm) layer depicted higher values as compared to AJL12 under the additive SQI. Triantafyllidis *et al*. (2018) and Yeilagi *et al*. (2021) also report a similar variance and conclude that SQI_w (weighted index) reported the optimal result and outperformed the SQI_a (additive index) as per their findings. Likewise, we recommend the values of the SQIw, as it agrees with the reports of land use causing alteration in the soil. This is further in conformity with our results, wherein the soil quality increased with the implementation of the fallow period. In the comparison of all sites, it is observed that AJL12 had the highest SQI, while JL had the lowest SQI. This is in agreement with Singh *et al*. (2013), who has reported on the higher SQI in forests (0.93) as compared to shifting cultivation sites (0.60). The comparison of the two soil quality index therefore concludes that the weighted SQI is better suited to monitoring soil quality in the present study sites. Similar reports on the utilization of SQI_w has been reported (Venkanna *et al*., 2014; Vasu *et al*., 2016).

3.4 SUMMARY AND CONCLUSION

From the study of both the selected soil parameters and SQI, it is evident that unsustainable soil practices degrade soil quality, while fallow periods regenerate soil quality. Shifting cultivation is vital for the socio-economic aspect of the indigenous inhabitants of Nagaland. However the findings of the chapter highlights the negative aspects of the reduction of fallow and increased cropping cycle. Such unsustainable means of resource utilization may threaten the livelihood security of the inhabitants. It is observed that the introduction of an adequate fallow period ensures vegetative regrowth and soil recovery. The introduction of bamboo in degraded Jhum fields is also reported to increases the rate of soil recovery. The finding of the soil physico-chemical properties highlight the degradation of soil at JL with elevated BD, reduced SOC, nutrients, and clay content as compared to sites AJL3, AJLB and AJL12. The introduction of bamboo in fallow significantly increases EC, SOC, N, Moisture, clay, CEC, TN, and reduced the BD levels. The result of the chapter

is in affirmation of our first hypothesis of "Shifting cultivation and length of fallow period affect soil quality". The short-term sustainable introduction of *Musa* cultivars at fallow lands may also significantly aid in the sequestration of carbon lost during Jhumming. Monitoring on the long term effects of *Musa* cultivars on the soil will also provide vital information for its effects on soil quality to ensure sustainable utilization.

The creation and selection of MDS for each sites also highlights the degradation of soil at JL. At JL, CEC, BD and clay are retained. At AJL3, SOC, moisture and pH; at AJL12, SOC and moisture; at AJLB, SOC and P_{av} was retained, respectively. These MDS represent the key soil variable of each sites. Furthermore, the weighted SQI_w provided more accurate results than the additive SQI_a among the different sites. There is an urgent need for an efficient and swift soil quality assessment and management in the region, and SQI may be one of the many tools to achieve this goal. We also conclude that MDS can be used to assess soil quality faster while at the same time reducing workload and costs. The implementation of SQI in the region may be utilized to generate soil quality index maps for researchers and policy makers. The data generated can be quickly disseminated to the ingenious inhabitant with fewer resources and time spent. The graphical nature of data presentation by utilizing the SQI may also aid in data dissemination. Such method will be crucial in monitoring and policy making for the stakeholders.

CHAPTER-4

AGRONOMIC PERFORMANCE OF *MUSA* CULTIVARS UNDER DIFFERENT FALLOW PERIOD

4.1 INTRODUCTION

India is the largest producer and consumer of banana. This crop is vital for the socio-economic aspect of the country, owing to its viable nutrition source and economic opportunities. Because of its versatile importance and utilization, it is aptly recognized as the plant of every virtue. Banana are fast growing herbaceous pants requiring high moisture content and a suitable soil medium for their growth (Grime, 1979). Their rapid establishment ensures livelihood security to the ingenious inhabitants from the economically weaker section. Thus the main goal of inventorying of the agronomic performance of banana lies in availability of cultivars with increased yield, greater suckering, reduced cycling phase, and optimized root systems (Brown *et al*., 2017). This can be estimated by the selection of key traits such as vegetative traits, fruit cycle and fruit yield (Uwimana *et al*., 2020). Murry and Das (2019) report on the critical role of banana cultivation in Nagaland. The study also highlights the present area, i.e., Mokokchung district, Nagaland, as the second largest producer of banana in the region. This simultaneously highlights the significant role of banana in maintaining livelihood security for the inhabitants. However, owing to the nature of the hilly area, the sites are naturally prone to erosions and are challenging to irrigate (Hossain, 2022). The dominant system of farming in the region, i.e., shifting cultivation, may make the environment unsuitable for the establishment and efficient production of bananas. Therefore, to ensure sustainable utilization and efficient production, there is an urgent need to understand the complex relationship between soil and agronomic performance to understand the argo-ecology of the cultivars (Van Leeuwen *et al*., 2004). Nyamamba *et al.* (2020) also highlight the challenges of high water and nutrient requirements for banana cultivation. This is concerning as reports on the negative effects of shifting cultivation on productivity, due to reduced fallow and cropping cycle, is well documented in other regions of the country (Rahman *et al*., 2012; Rahman *et al*., 2014). However, such information on the relationship between soil and the productivity of *Musa* cultivar is not available in the region of Nagaland. As agriculture is deeply rooted in the socio-cultural roots of the indigenous inhabitants, a deep understanding of the various agro-

ecological processes is required to ensure sustainable and efficient production to compact the challenges modern agricultural practices face (Wezel *et al*., 2009). One way to ensure livelihood securities under the region is to select the best performing suitable cultivar. This can be achieved by evaluating the agronomic performance of the cultivars. Such findings are also vital for establishing the relationship between genotype and phenotype for various breeding programs **(**Okech *et al*., 2004). Therefore, with growing awareness on the effects of Jhumming and falow on productivity, the present chapter attempts to record whether Jhum land and fallow lands of different periods significantly alter the agronomic performance of the two selected *Musa* cultivars. The study also establishes critical limits of soil quality indicators for the cultivars.

4.2 RESULTS

Fig.6.1 and **Fig. 6.2** illustrate the various morphological features of the two selected *Musa* cultivar i.e Aot Mungo (Ao Naga) and Atsu Mungo (Ao Naga) from Mokochung, Nagaland.

4.2.1 Agronomic performance of Aot Mungo

The result of the agronomic trait of Aot Mungo is presented in **Fig. 7.1**. The result of the one way ANOVA with post-hoc DMRT test to check if the difference is significant at 5% level (p=<0.05) is presented in **Table 6**. Under the vegetative traits, the following observations were recorded. Plant girth was highest at site JL and AJL3 with a value of 67.00±2.16 cm. The lowest value was recorded at AJL12 with a value of 61.33±2.26 cm. It is reported that plant girth did not vary significantly between the study sites (F=2.734, p=0.114). Plant height was recorded highest at AJL3 (427.00±2.94 cm), and least value was recorded at AJL12 (311.33±15.36 cm). It is observed that plant height varied significantly across the study sites (F=53.910, p<0.001). Similarly, sucker production varied significantly between the sites (F=4.33, p=0.043), with the highest value of 4.3 recorded at AJL12. The lowest value of 2.3 was recorded at site AJL3. For the number of functional leaves, the highest value was recorded at AJL12 (14.33±0.48), while the lowest value was recorded at JL (9.6±0.94). The values were significantly different across the study sites (F=14.53, p=0.001). Under the maturity traits, it is reported that the plant cycle was reported to be significantly lowered at AJLB (440.67±20.67) and AJL12 (491.33±53.42), while it was highest at JL (639.67±27.53), with F=13.49, p=0.002, respectively. Similarly, days to

flowering was also reported to be lowest at AJLB (357.00±33.79) and AJL12 (395.67±47.30) and highest at JL (491.00±50.76). The differences were statistically significant across the study sites (F=5.144, *p*=0.028). No significant variation was observed for the period between flowering to harvesting in the present study (F=0.411, *p*=0.750). The lowest value was observed at AJLB (83.67±16.49) and AJL12 (95.67±6.23), respectively.

Under the fruit yield traits category, the bunch weight varied significantly between sites (F=69.547, *p*=<0.001), with the highest value recorded at AJL12 (22.57±0.73 kg), followed by AJLB (20.37±0.52 kg), and the lowest value at JL (14.50±0.37 kg). A significant variation was also observed for the number of fruits (F=10.02, *p*=0.004), and the number of hands (F=9.43, *p*=0.005). The highest value was recorded at AJL12, and lowest at JL, respectively. The fruit filling index (F=12.00, *p*=0.002) also varied significantly between the sites with higher values at AJLB (0.243±0.06) and AJL12 (0.235±0.001). The expected fruit yield varied significantly between the sites (F=74.78, *p*=<0.001) with significantly reduced value at JL (0.0090±0.01 t ha^{-1} $year^{-1}$) and increased with the introduction of fallow and vegetation at AJL3, AJLB and AJL12, respectively. Lastly, the relative yield was highest at AJL12 (99.99±3.24) and lowest at JL (64.25±1.65). The differences were statistically significant (F=69.54, *p*=<0.001).

4.2.2 Agronomic performance of Atsu Mungo

The result of the agronomic trait of Atsu Mungo is presented in **Fig.7.2**. The result of the one way ANOVA with post-hoc DMRT test to check if the difference is significant at 5% level (*p*=<0.05) is presented in **Table 7**. Under the vegetative traits, the plant girth did not vary significantly between the different study sites (F=2.767, *p*=0.111). However, the highest value was recorded at site JL (47.3±3.68 cm), while lowest value were reported at AJLB (41.33±1.88 cm) and AJL12 (42.66±0.94 cm), respectively. Plant height varied significantly between the sites (F=18.62, *p*=0.001), with the highest value at AJL3 (345±12.24 cm) and the lowest value (290.3±11.47 cm) at JL. Similarly, sucker production varied significantly between the study sites (F=6.074, *p*=0.019). The highest value of 4.6±1.24 was recorded at site AJL12, while the lowest value of 2±0.001 was recorded at JL. For the number of functional leaves, the highest value was recorded at AJL12 (13.33±1.69), while the lowest value was recorded at JL (7.6±0.94) with F=8.160, *p*=0.08, respectively. Under the maturity traits of Atsu Mungo, the plant cycle was reported to be lowest at AJL12 (435±24.91), while it was highest at JL (672±7.78). The differences were statistically

significant (F=34.779 *p*=<0.001). Days to flowering were also reported to be significantly lower at AJL12 (337.66±23.44) and highest at JL (520±45.72), (F=15.760, *p*=0.001). No significant variation is observed for the period between flowering to harvesting (F=3.854, *p*=0.056). The highest period between flowering to harvesting was reported at JL (137±50.61), while the lowest period was reported at AJL12 (97.33±1.69).

Under the fruit yield traits, the bunch weight varied significantly between sites (F=151.986, *p*=<0.001), with the highest value at AJL12 (17.33±0.47 kg) and the lowest at JL (9.68±0.60 kg). No significant variation was observed between the number of fruits and the number of hands. The highest value of number of fruits was recorded at AJLB (67.00±2.16) and AJL12 (55.67±35.02), while lower values were reported at AJL3 (54.00±13.36) and JL (52.33±1.19). The higher value of number of hands was recorded at AJL12 (6.00±0.010). The values of the fruit filling index (F=23.52, *p*=<0.001) and the expected fruit yield (F=62.16, *p*=<0.001) varied significantly between the study sites. The highest fruit filling index was recorded at AJL12 (0.1782±0.001), and least at JL (0.00622±0.01). Similarly, highest value of expected fruit yield was observed at AJL12 (0.0160±0.001 t ha^{-1} $year^{-1}$) and lowest at JL (0.0057±3.25 t ha^{-1} $year^{-1}$). Lastly, the relative yield was highest at AJL12 with a value of 100±2.72, while it was lowest at JL 55.87±0.35 (F=151.98, *p*=<0.001).

4.2.3 Comparison of agronomic performance of Aot Mungo and Atsu Mungo under the study sites

Table 8 depicts the result of the independent-samples T-test between the two cultivars at different sites with F-values and *p*-values. Under the vegetative traits, significantly higher plant girth was observed for the Aot Mungo (65.083±3.39 cm) as compared to Atsu Mungo (45.833±6.14 cm). Similarly, higher values of plant height were recorded for Aot Mungo (365.667 ±54.13 cm) as compared to Atsu Mungo (320.250±22.43 cm). Higher values of sucker and functional leaves is reported for Aot Mungo as compared to Atsu Mungo. On comparison of the maturity traits, Aot Mungo depicted a higher value of 546.083±94.43 days as compared to Atsu Mungo with a value of 541.000±105.38 days. Higher values of Planting to flowering and Flowering to harvest is recorded for Aot Mungo as compared to Atsu Mungo. On comparison of the fruit yield traits, higher values of bunch weight for Aot Mungo (18.358±3.45 kg) as compared to Atsu Mungo (13.354±3.05 kg). Number of fruits and hands were also higher for Aot Mungo with values of 142.250±59.45 and 10.250±1.68, respectively. Similarly, a higher fruit filling index, expected fruit yield and

relative yield are reported for Aot Mungo as compared to Atsu Mungo. The present study also reporst that of all the various traits, only plant girth (p=0.041), plant height (p=<0.001), number of fruits (p=<0.001) and number of hands (p=0.006) were reported to be statistically significant.

4.2.4 Critical limits of soil quality indicators for Aot Mungo

The result of the simple linear regression between the different soil parameters and relative yield for obtaining 40% and 80% of the maximum possible yield for Aot Mungo are depicted in **Fig. 8.1** and **Fig. 8.2**. The r^2 values and critical limits are presented in **Appendix II**. For pH, a value of 5.9 and 5.2 (r^2 = 0.8609), respectively are reported as the threshold values. EC values were observed to be 0.175 dS m^{-1} and 0.42 dS m^{-1} (r^2 = 0.895). The upper and lower critical limits of SOC are reported as 0.42% and 2.43% (r^2 = 0.9192). N values were reported to be 137.30 Kg ha^{-1} and 385.36 Kg ha^{-1}(r^2 = 0.9465), respectively for obtaining the 40% and 80% of maximum yield. In the case of K, the lower and upper critical limits values were 34.84 Kg ha^{-1} and 151.43 Kg ha^{-1} (r^2 = 0.9871). The P values were reported as 11.15 Kg ha^{-1} and 27.35 Kg ha^{-1}, (r^2 = 0.9453). The moisture content values obtained from the critical limits were 16.80% and 41.13% (r^2 = 0.9868). BD values were 2.54 g cm^{-3} and 1.472 g cm^{-3}, (r^2 = 0.884) respectively, and were reported as the critical limits. Clay content values were 14.766% and 28.22% (r^2 = 0.9335). CEC values were 3.77 meq100g^{-1} and 22.97 meq100g^{-1} (r^2 = 0.9563), respectively, for obtaining the lower and upper critical limits. TN values was 0.422 % and 1.32 % (r^2=0.9569) for the lower and upper limits. Sand content was 61 % and 43.86 % for the upper and lower critical limits (r^2=0.9874). Lastly, for silt a value of 19.40% and 26.77% was obtained for the upper and lower critical limits (r^2= 0.9124). Based on this data, the different sites are categorized under different classes depicted in **Table 9.1** for Aot Mungo.

4.2.4 Critical limits of soil quality indicators for Atsu Mungo

The result of the simple linear regression between soil parameters and relative yield for obtaining 40% and 80% of the maximum possible yield for Atsu Mungo are depicted in **Fig. 9.1** and **Fig 9.2**, respectively. The r^2 values and critical limits are presented in **Appendix II**. For pH, a value 5.78 and 5.20 (r^2 =0.9284), respectively are reported as the threshold values. EC values were recorded at 0.057 dS m^{-1} and 0.48 dS m^{-1} (r^2 =0.9406). The upper and lower critical limits of SOC are reported as 0.80% and 2.62% (r^2 =0.9761). N values were reported to be 196.09 Kg ha^{-1} and 407.11 Kg ha^{-1} (r^2 =0.9002), respectively for

obtaining the 40% and 80% of maximum yield. In the case of K, the lower and upper critical limits values were 62.43 Kg ha^{-1} and 161.65 Kg ha^{-1} (r^2 =0.9398). The P values were reported as 14.62 Kg ha^{-1} and 28.80 Kg ha^{-1}, (r^2 =0.9518). The moisture content values obtained from the critical limits were 21.99% and 43.31% (r^2 =0.9956). BD values were reported as 2.31 g cm^{-3} and 1.37 g cm^{-3}, (r^2 =0.8900) respectively, and were reported as the critical limits. Clay content values were 17.46% and 29.44% (r^2 = 0.9725). And lastly, CEC values were 8.18 meq100g^{-1} and 24.66 meq100g^{-1} (r^2 =0.9258), respectively, for obtaining the lower and upper critical limits. TN values was 0.62 % and 1.40 % (r^2=0.946) for the lower and upper limits. Sand content was 57.01 % and 42.35 % for the upper and lower critical limits (r^2=0.9493). Lastly, for silt a value of 20.95% and 27.43% was obtained for the upper and lower critical limits (r^2= 0.9271).Based on this data, the different sites are categorized under different classes depicted in **Table 9.2** for Atsu Mungo.

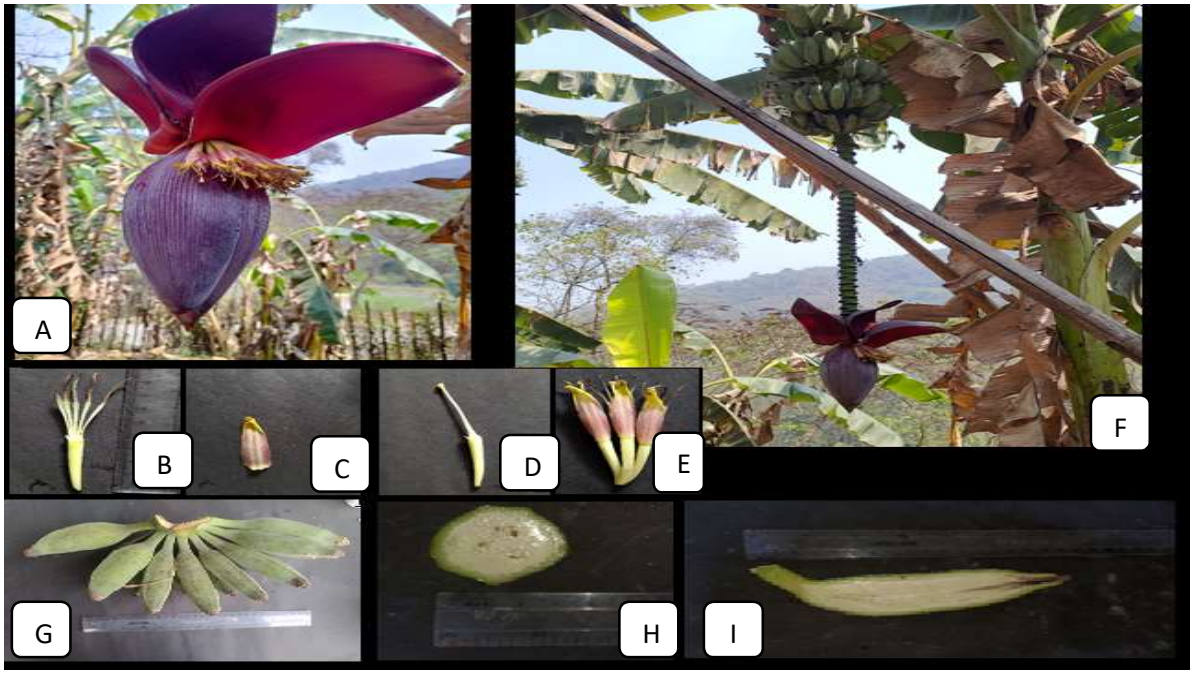

Fig. 6.1: *Musa* cultivar 1: Aot Mungo (Ao Naga) with various floral parts in picture. **A:** Banana inflorescence. **B:** Stamens. **C:** Tepal. **D:** Style and stigma. **E:** Male Flowers. **F:** Banana flowering. **G:** Banana bunch. **H:** Transverse section of fruit. **I:** Longitudinal section of fruit.

Fig. 6.2: *Musa* cultivar 2: Atsu Mungo (Ao Naga) with various floral parts in picture. **A:** Banana inflorescence. **B:** Stamens. **C:** Tepal. **D:** Style and stigma. **E:** Male Flowers. **F:** Banana flowering. **G:** Banana bunch. **H:** Transverse section of fruit. **I:** Longitudinal section of fruit.

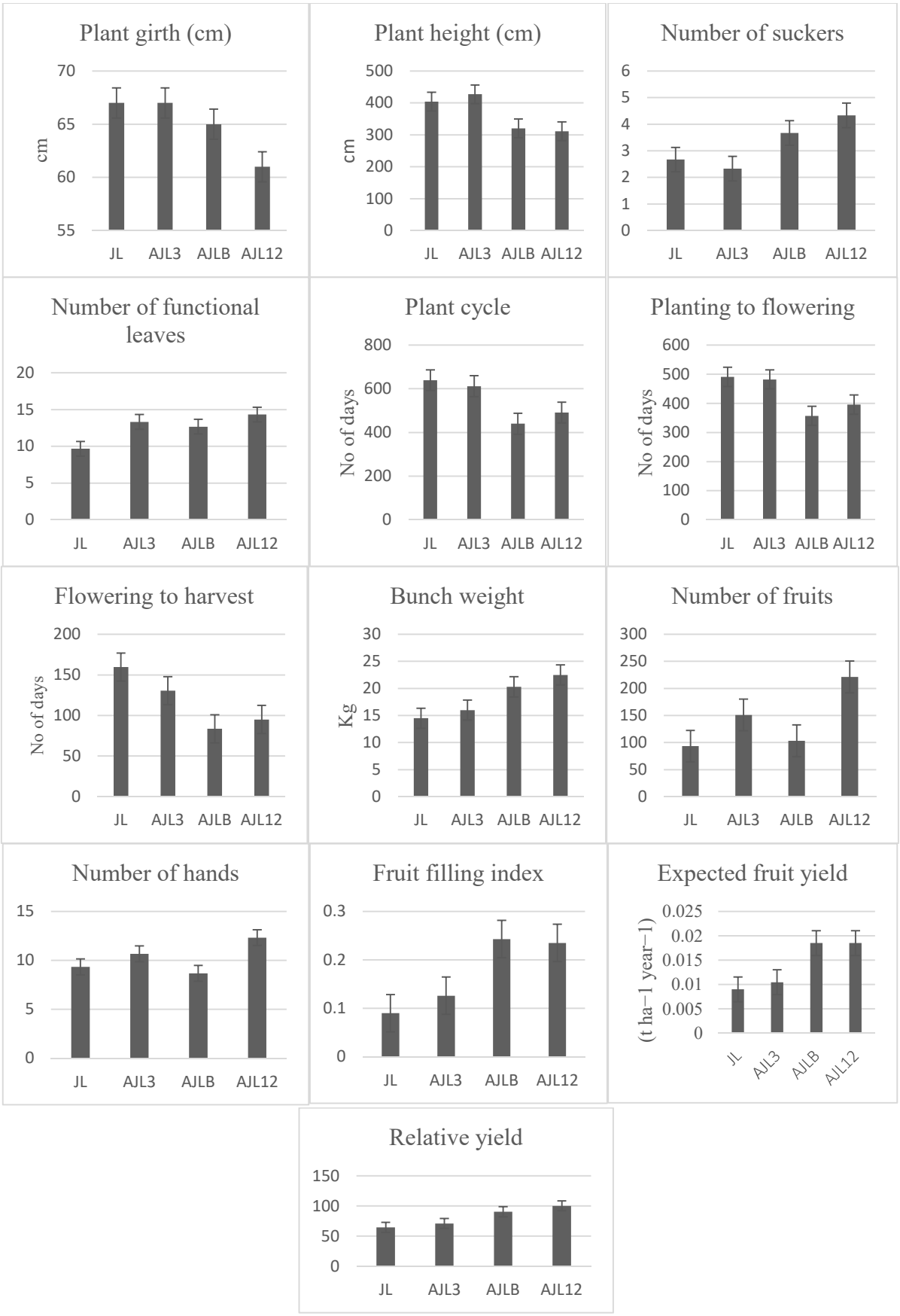

Fig.7.1: Agronomic traits of Aot Mungo from the study sites

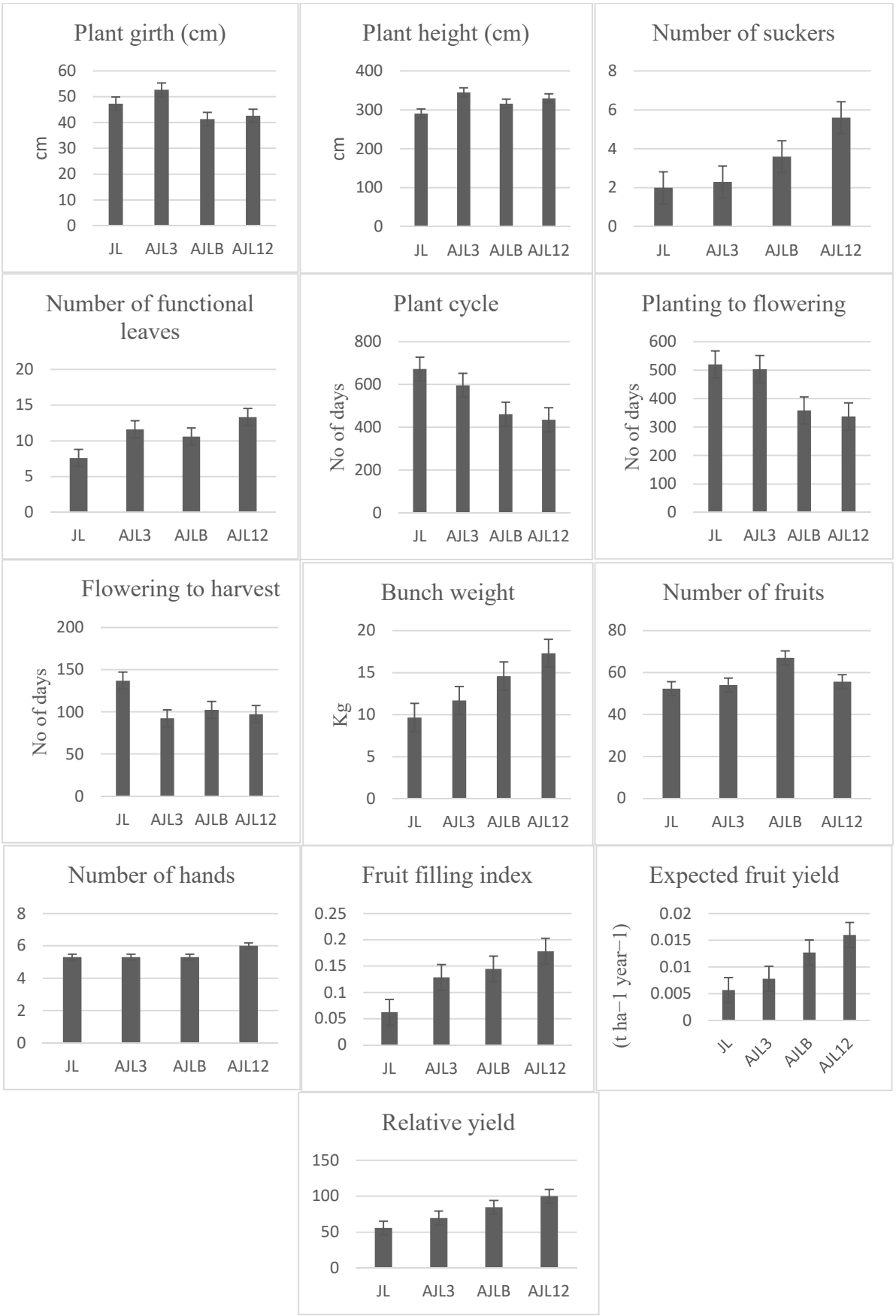

Fig. 7.2: Agronomic traits of Atsu Mungo from the study sites

Table 6: Agronomic trait of Aot Mungo from the four study sites

Agronomic trait		JL	AJL3	AJLB	AJL12
Vegetative	Plant girth (cm)	67.00±2.16^{b}	67.00±2.16^{b}	65.00±2.16^{ab}	61.33±2.62^{a}
	Plant height (cm)	404.00±13.36^{b}	427.00±2.94^{b}	320.33±9.10^{a}	311.33±15.36^{a}
	Number of suckers	2.67±0.48^{a}	2.33±0.47^{a}	3.67±0.47^{ab}	4.33±0.94^{b}
	Number of functional leaves	9.67±0.94^{a}	13.33±0.94^{b}	12.67±0.47^{b}	14.33±0.48^{b}
Maturity	Plant cycle (days)	639.67±27.53^{b}	612.67±36.80^{b}	440.67±20.67^{a}	491.33±53.42^{a}
	Planting to flowering	491.00±50.76^{d}	482.00±53.76^{bc}	357.00±33.79^{a}	395.67±47.30^{ab}
	Flowering to harvest(days)	159.75±24.78^{a}	130.67±89.75^{a}	83.67±16.49^{a}	95.67±6.23^{a}
Fruit yield	Bunch weight (kg)	14.50±0.37^{a}	16.00±0.81^{b}	20.37±0.52^{c}	22.57±0.73^{d}
	Number of fruits	93.33±12.22^{a}	151.00±50.20^{a}	103.33±7.13^{a}	221.33±1.88^{b}
	Number of hands	9.33±0.47^{ab}	10.67±0.47^{bc}	8.67±0.47^{a}	12.33±1.24^{c}
	Fruit filling index	0.090±0.02^{a}	0.126±0.03^{a}	0.243±0.06^{b}	0.235±0.001^{b}
	Expected fruit yield(t ha^{-1} year^{-1})	0.0090±0.01a	0.01045±0.001^{a}	0.0185±0.01^{b}	0.0185±0.001^{b}
	Relative yield	64.25±1.65^{a}	70.90±3.61^{b}	90.25±2.32^{c}	99.99±3.24 ^{d}

Values are expressed as Mean ± standard deviation. Values in the same row with different superscripts are significantly different at 5% level by Duncan's multiple range test (p=<0.05).

Table 7: Agronomic trait of Atsu Mungo from the four study sites

Agronomic trait		JL	AJL3	AJLB	AJL12
Vegetative	Plant girth (cm)	47.3 ± 3.68^{ab}	52 ± 7.07^{b}	41.33 ± 1.88^{b}	42.66 ± 0.94^{a}
	Plant height (cm)	290.3 ± 11.47^{a}	345 ± 12.24^{c}	316 ± 4.54^{b}	329.66 ± 7.76^{bc}
	Number of suckers	$2\pm.001^{a}$	2.33 ± 0.47^{a}	3.66 ± 0.47^{ab}	4.6 ± 1.24^{b}
	Number of functional leaves	7.6 ± 0.94^{a}	11.66 ± 0.47^{b}	10.66 ± 1.24^{b}	13.33 ± 1.69^{b}
Maturity	Plant cycle (days)	672 ± 7.78^{c}	596 ± 25.15^{b}	461 ± 39.82^{a}	435 ± 24.91^{a}
	Days to flowering	520 ± 45.72^{b}	503.66 ± 24.52^{b}	358.66 ± 29.04^{a}	337.66 ± 23.44^{a}
	Flowering to harvest(days)	137 ± 50.61^{b}	92.33 ± 8.65^{a}	102.33 ± 11.61^{a}	97.333 ± 1.69^{a}
Fruit yield	Bunch weight (kg)	9.68 ± 0.60^{a}	11.73 ± 0.37^{b}	14.67 ± 0.47^{c}	17.33 ± 0.47^{d}
	Number of fruits	52.33 ± 19.18^{a}	54.00 ± 13.36^{a}	67.00 ± 2.16^{a}	55.67 ± 35.02^{a}
	Number of hands	5.33 ± 1.24^{a}	5.33 ± 0.47^{a}	5.33 ± 0.47^{a}	6.00 ± 0.010^{a}
	Fruit filling index	0.0622 ± 0.01^{a}	0.1285 ± 0.01^{b}	0.1447 ± 0.10^{b}	0.1782 ± 0.001^{c}
	Expected fruit yield(t ha^{-1} $year^{-1}$)	0.0057 ± 3.25^{a}	$0.0078\pm.001^{b}$	0.0127 ± 0.01^{c}	0.0160 ± 0.001^{d}
	Relative yield	55.87 ± 0.35^{a}	67.705 ± 2.17^{b}	84.63 ± 2.72^{c}	100 ± 2.72^{d}

Values are expressed as Mean ± standard deviation. Values in the same row with different superscripts are significantly different at 5% level by Duncan's multiple range test (p=<0.05).

Table 8: Results of independent-samples T-test between the two cultivars at different sites with F-values and *p*-values

Agronomic traits		**Aot Mungo**	**Atsu Mungo**	**F-value**	***p*-value**
Vegetative	Plant girth (cm)	65.083±±3.39	45.833±6.14	4.709	0.041
	Plant height (cm)	365.667 ±54.13	320.250±22.43	32.031	<0.001
	Number of suckers	3.250±1.05	3.167±1.33	.638	0.433
	Number of functional leaves	12.500±1.97	10.833±2.48	.326	0.574
Maturity	Plant cycle (days)	546.083±94.43	541.000±105.38	.368	0.550
	Planting to flowering	438.750±84.06	425.500±87.74	.424	0.522
	Flowering to harvest(days)	107.333±53.17	115.500±43.017	.476	0.497
Fruit yield	Bunch weight (kg)	18.358±3.45	13.354±3.05	.825	0.374
	Number of fruits	142.250±59.45	57.167±20.57	25.715	<0.001
	Number of hands	10.250±1.68	5.492±0.48	9.137	0.006
	Fruit filling index	0.419±0.81	0.128±0.04	3.998	0.058
	Expected fruit yield(t ha^{-1} $year^{-1}$)	0.014±0.005	0.011±0.004	1.083	0.309
	Relative yield	81.351±15.31	77.058±17.63	.317	0.579

Values are expressed as Mean ± standard deviation. Significance level (*p*=<0.005)

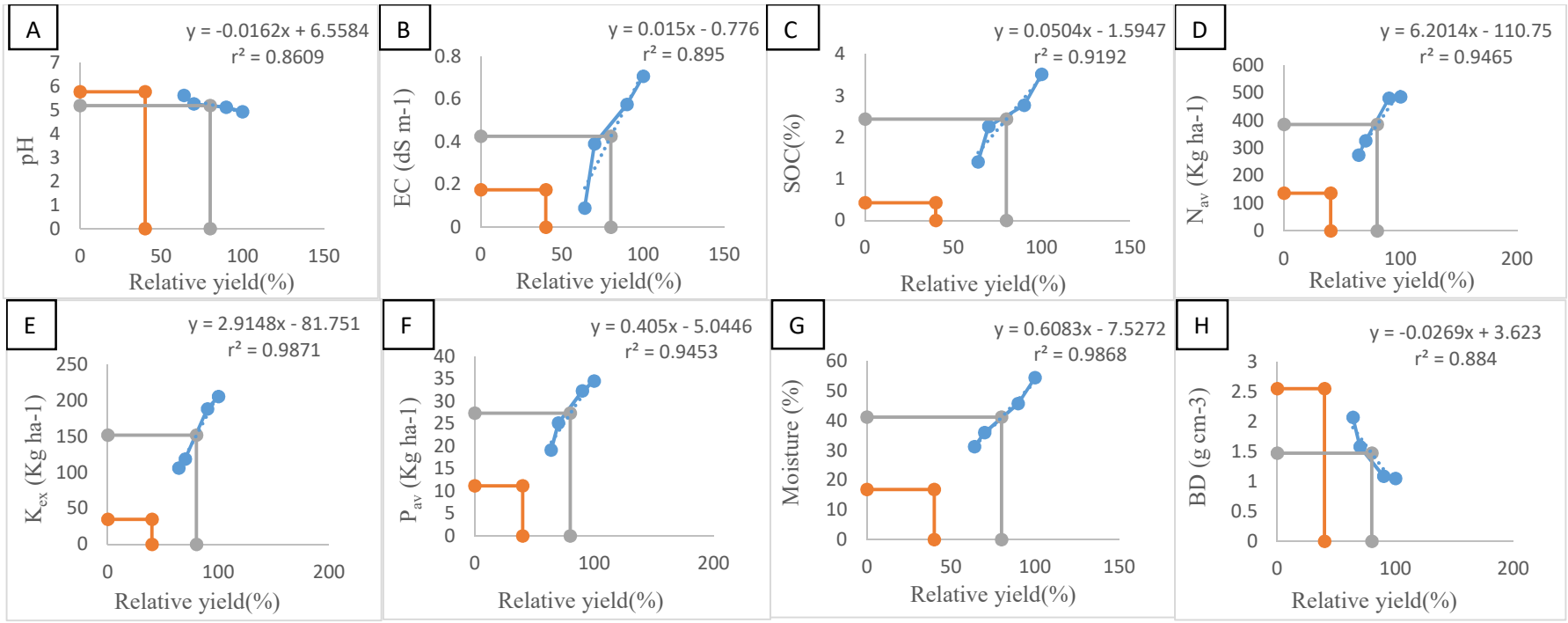

Fig 8.1: Critical limits of soil quality indicators for Aot Mungo **A:** pH **B:** Electrical conductivity **C:** Soil organic carbon **D:** Available nitrogen **E:** Available potassium **F:** Available phosphorus **G:** Soil H: Bulk density

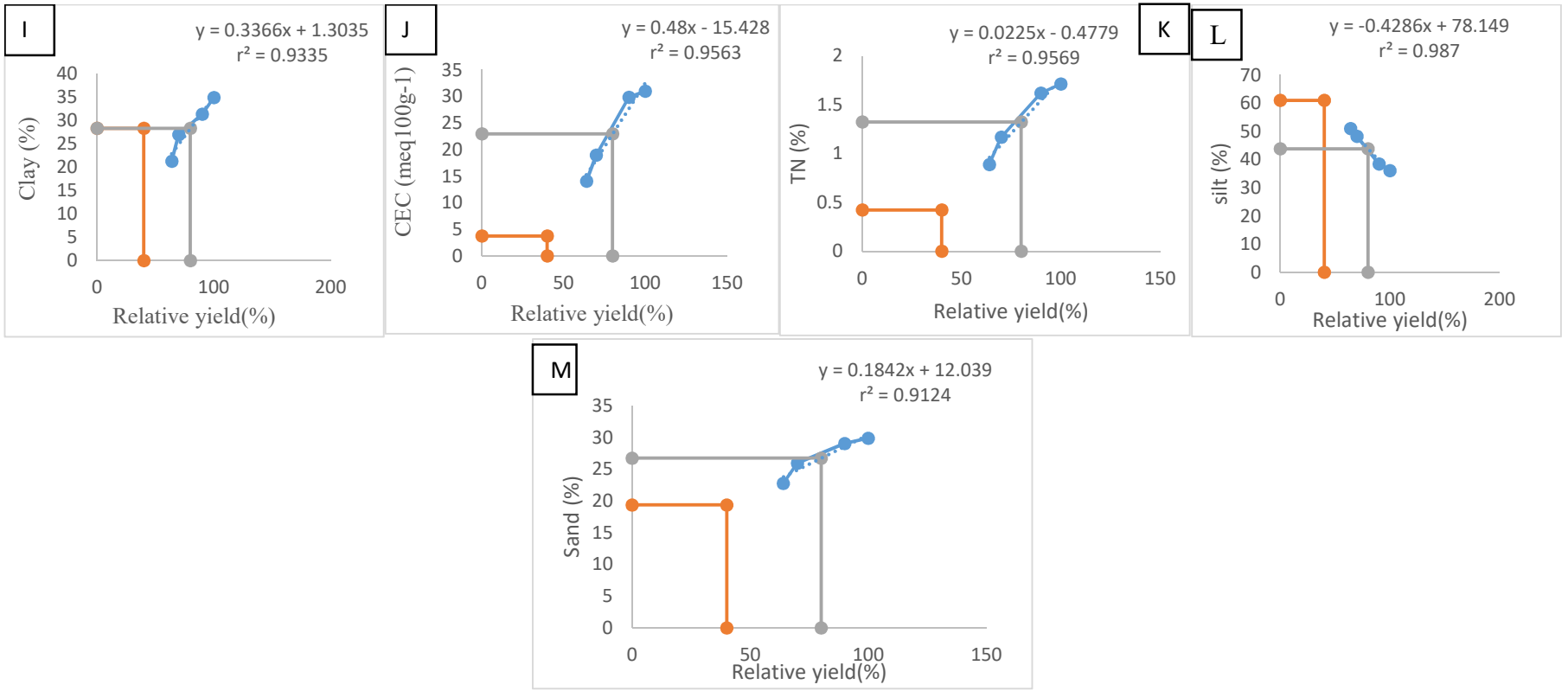

Fig 8.2: Critical limits of soil quality indicators for Aot Mungo **I:** Soil clay content **J:** Cation exchange capacity **K:** Total Nitrogen **L:** Silt content **M:** Sand content

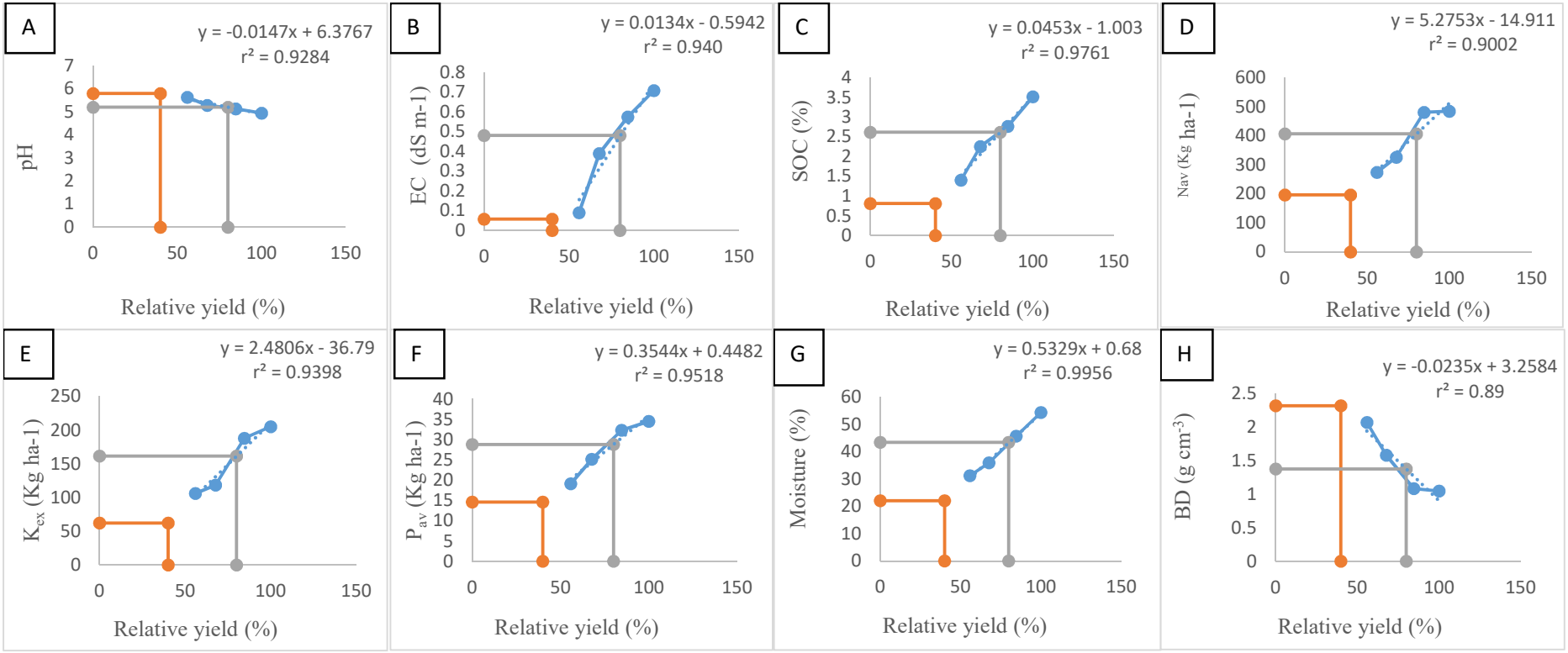

Fig 9.1: Critical limits of soil quality indicators for Atsu Mungo **A:** pH **B:** Electrical conductivity **C:** Soil organic carbon **D:** Available nitrogen **E:** Available potassium **F:** Available phosphorus **G:** Soil **H:** Bulk density

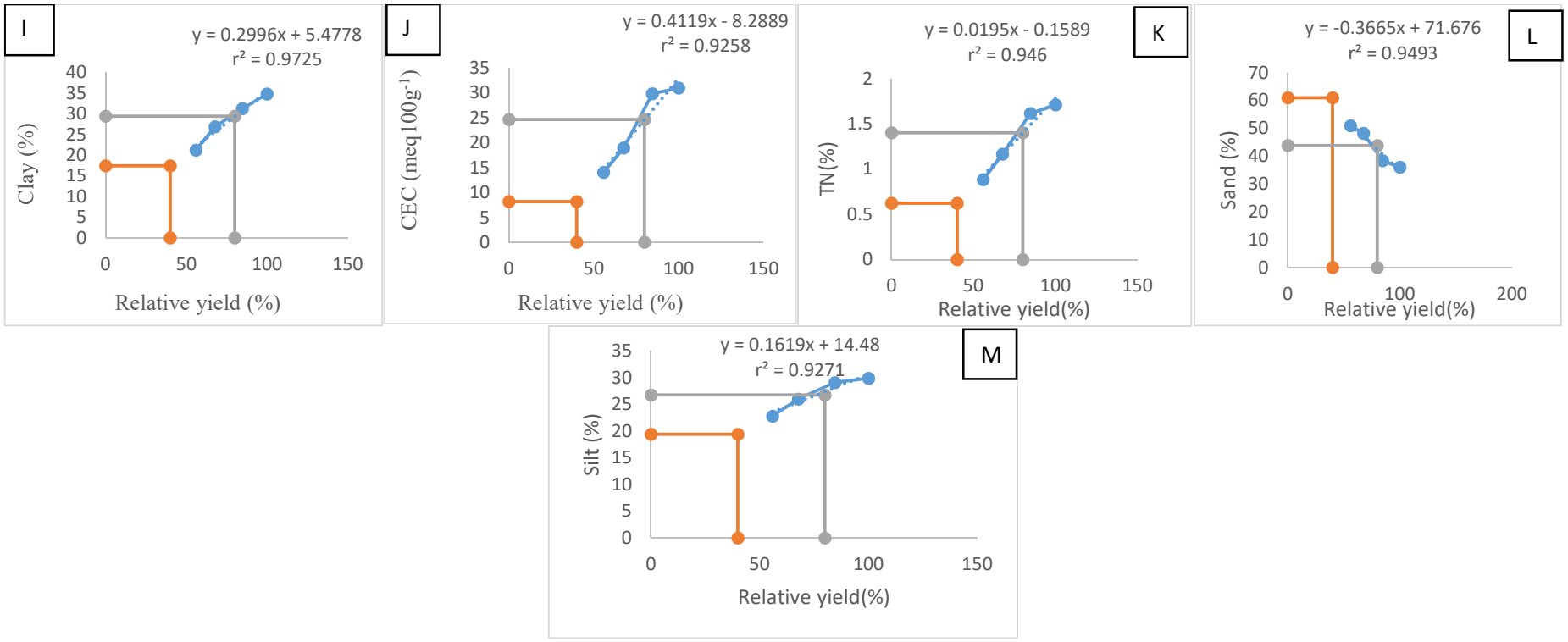

Fig 9.2: Critical limits of soil quality indicators for Atsu Mungo **I:** Soil clay content **J:** Cation exchange capacity **K:** Total Nitrogen **L:** Silt content **M:** Sand content

Table 9.1: Classification of soil based on the critical limits of soil quality indicators for Aot Mungo

Site	pH	EC ($dS\ m^{-1}$)	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	TN (%)	Sand (%)	Silt (%)
JL	5.63	0.11	1.4	274.29	106.01	19.11	31.15	2.07	21.2	14.06	0.885	50.95	22.79
AJL3	5.12	0.39	2.25	326.5	118.34	25.11	35.86	1.58	26.9	18.96	1.166	48.25	26.00
AJLB	5.13	0.57	2.76	480.59	188	32.3	45.63	1.08	31.28	29.82	1.616	38.44	29.11
AJL12	4.93	0.7	3.51	484.88	205	34.49	54.3	1.04	34.84	30.95	1.710	36.09	29.91

RED=Low, Yellow=Moderate, Green=Adequate

Table 9.2: Classification of soil based on the critical limits of soil quality indicators for Atsu Mungo

Site	pH	EC ($dS\ m^{-1}$)	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	TN (%)	Sand (%)	Silt (%)
JL	5.63	0.11	1.4	274.29	106.01	19.11	31.15	2.07	21.2	14.06	0.885	50.95	22.79
AJL3	5.12	0.39	2.25	326.5	118.34	25.11	35.86	1.58	26.9	18.96	1.166	48.25	26.00
AJLB	5.13	0.57	2.76	480.59	188	32.3	45.63	1.08	31.28	29.82	1.616	38.44	29.11
AJL12	4.93	0.7	3.51	484.88	205	34.49	54.3	1.04	34.84	30.95	1.710	36.09	29.91

RED=Low, Yellow=Moderate, Green=Adequate

4.3 DISCUSSION

4.3.1 Agronomic performance of the two selected *Musa* cultivars

Based on the agronomic performance of both *Musa* cultivars (**Tables 6** and **7**), the present study reports on the increased rate of flowering, presence of additional functional leaves, production of more sucker, and increased yield at AJLB and AJL12 as compared to sites JL and AJL3. It is observed during the study that there was significantly higher moisture and clay content at sites AJLB and AJL12 (**Tables 9.1** and **9.2**). This soil condition may be one factor favoring a faster flowering period of the cultivars at sites AJLB and AJL12. Cardone *et al*. (2020) report on a faster flowering rate under soils with higher clay and moisture content. Wagner *et al*. (2014) also opined that the phenotypic plasticity of flowering plants is controlled by soil factors and microbial populations. Concerning the results of the elevated number of functional leaves under AJLB and AJL12, Lee *et al*. (2018), similarly remarked on the increase of the number of leaves with an increase in soil nutrients (p=<0.001). There exist a positive relationship between leaf photosynthetic rate and N, C: N, and C: P levels (Li *et al*., 2022). Therefore, in the present study, increased soil fertility at AJLB and AJL12 leads to an increase in plant girth and height and more functional leaves. Similarly, increased soil quality at sites AJLB and AJL12 also increases yield. Wapongnungsang *et al*. (2021) similarly report that rice yields were significantly higher under fallow age 15 as compared to fallow age 10 (p=<0.01). This increase in yield is due to increased P levels, organic matter input and increased microbial community. The present study also reports on the significantly reduced moisture content at sites JL and AJL3 as compared to sites AJLB and AJL12. The presence of early water stress is reported to significantly diminish the fruiting body's size and weight (Girona *et al*., 1993). For sucker production, different factors such as ploidy, environment, space, season, and depth affect its rate and number (Siddhesh and Sajan, 2015). Sucker production and leaf area, in particular, have been reported to exhibit a positive relationship with N levels of soil (Chowdhury *et al*., 2020). Therefore higher leaf production in sites AJLB and AJL12 may also explain the increased sucker production under these sites. Bananas are rapidly growing herbaceous plants. Hence they require favorable environment for their establishment. However, it is reported that plants with rapid growth traits cannot adapt to unsuitable environments, leading to decreased growth as the soil quality deteriorates (Grime, 1979). Therefore, it is critical to inventory and understand the agronomic performance of banana production programs to ensure sustainable economic

returns while simultaneously safe guarding the environment. Nyamamba *et al*. (2020) similarly remark on the increased economic importance of bananas because of to their reliable markets, high returns and lower production cost.

In comparing the agronomic performance of the two *Musa* cultivars, significantly higher values of plant girth, plant height, number of fruits, and number of hands under the Aot Mungo as compared to Atsu Mungo was reported. This depicts the increased agronomic performance of Aot Mungo cultivar over Atsu Mungo in the region. Such increased performance positively affects the livelihood security of its cultivators. This also depicts the increased adaptation of the Aot cultivar in particular to abiotic stresss and biotic stress present in the environment (Futakuchi *et al*., 2003; Kashiwagi *et al*., 2005). Such increased tolerance and performance are vital in the selection of parents for various plant breeding programs.

4.3.2 Critical limits of soil quality indicators

The establishment of soil quality indicators is vital for achieving efficient productivity and sustainable management goals (Biswas *et al*., 2017). During the present study, the critical limits for the two *Musa* cultivars were established (**Fig. 8.1**, **Fig 8.2**, **Fig 9.1** and **Fig. 9.2**). Based on the data obtained from the critical limits, the present study categorizes the different sites as either in Low (<40%), Moderate (40-80%), or Adequate quality (>80%). The findings of the current study report that both *Musa* cultivars performed in the order JL<AJL3<AJLB<AJL12. For Both *Musa* cultivars all soil parameters were under the adequate category for sites AJLB and AJL12, respectively (**Tables 9.1** and **9.2**). Under the Aot Mungo, it is observed that at site JL, EC was under the low category while the other soil parameters were in the moderate category. At AJL3, all soil parameters besides pH was grouped as moderate category for Aot Mugno. Soil pH was under the adequate category for Aot Mungo at AJL3.

For Atsu Mungo, all soil parameters at site JL were under the moderate category. At AJL3, pH and clay were under the adequate category, while the remaining parameters were grouped as moderate. Based on the critical limits, the present findings report that the selected *Musa* cultivars display decreased plant performance at sites JL and AJL3 when compared to sites AJLB and AJL12 (**Tables 6** and **7**). The decreased plant performance at JL and AJL3 is due to reduced levels of soil nutrients and lowered litter input and mineralization. The present findings are supported by Datta and Singh (2012), who report

that a fallow period (<5) displayed a reduction in soil nutrients and a lowered yield with a ratio of energy output (4.6-9.8), as compared to fallow land of age 15 (25.6). The construction of the critical limits of the sites also display the positive effects of bamboo on soil restoration. The present study report increased SOC, N, P, moisture, and reduction in BD values at the site supplemented with bamboo (AJLB) as compared to natural fallow (AJL3) as shown in **Tables 9.1** and **9.2**. The present findings is supported by Shia *et al*. (2017), who report on increased SOC, moisture, nutrient mineralization and decreased BD (30%) under bamboo plantations soil. The workers report that the positive effects of bamboo on soil are due to their elevated microbial biomass (8-10 times higher), a byproduct of efficient SOC utilization by the microbial community. Similar work on the positive effects of bamboo on degraded Jhum soils has been reported (Arunachalam and Arunachalam, 2002; Mishra *et al*., 2014; Shilla and Mir, 2017).

4.4 SUMMARY AND CONCLUSION

The study on the agronomic performance of the two selected *Musa* cultivars under Jhum and fallow land provide vital insight into the relationship between soil and productivity of the cultivars in Mokokchung district, Nagaland. From the result of the agronomic trait of Aot Mungo, better vegetative traits, maturity and fruit yield at AJL12 and AJLB as compared to JL and AJL3 were reported. The cultivar displayed significantly reduced number of plant cycle at AJL12 (491.33±50.76) and AJLB (440.67±20.67), increased sucker at AJL12 (4.33±0.94) and AJLB (3.67±0.47), and elevated relative yield i.e, AJL12 (99.99±3.24) and AJLB (90.25±2.32). The agronomic performance of the Aot Mungo at JL, in particular, was low. Similarly, for Atsu Mungo, the present study report on the significant positive effect of fallow in positively affecting the agronomic traits of cultivar Atsu Mungo. The cultivar displayed lowered plant cycle at AJ12 (435±24.91) and AJLB (461±39.82), higher suckers at AJL12 (4.6±1.24) and AJLB (3.66±0.47), and higher relative yield at AJL12 (100±2.72) and AJLB (84.6±2.72). This highlights the positive effect of fallow on productivity and also highlights the restorative potential of *B. tulda* in soil recovery of degraded Jhum lands. The study also depicts the increased agronomic performance of Aot Mungo cultivar over Atsu Mungo in the region. This cultivar may be utilized for ensuring the livelihood securities under the region for the indigenous inhabitants.

The establishment of the critical limits of soil quality indicators also allows for the classification of land best suited for the specific cultivar. The present study reports that for Aot Mungo, the soil was in the moderate category for all soil parameters while it was under the low category for EC at JL. At AJL3, besides pH in the adequate category, all soil parameters were in the moderate category. The introduction of fallow and bamboo elevated the soil critical limits in the adequate category (AJLB and AJL12). Similarly, Atsu Mungo depicted a similar trend of moderate quality soil at JL and AJL3, whereas soil were under the adequate category at AJLB and AJL12. The findings of the chapter highlights on the negative after effects of reduced fallow and increased cropping cycle on agronomic performance of *Musa* cultivars. Such unsustainable means of farming practices will negatively impact the economic aspect of production thereby affecting livelihood security. The construction of such critical limits of soil quality of indicators in the region will also be a valuable tool in future crop monitoring and evaluation programs. The result of the chapter is in affirmation with our second hypothesis of "Shifting cultivation and fallow length alter the agronomic performance of *Musa* cultivars."

CHAPTER-5

PROXIMATE COMPOSITION OF THE TWO SELECTED *MUSA* CULTIVARS

5.1 INTRODUCTION

Ensuring food security in a region is not guaranteed by achieving a desirable yield alone. Another key factor in determining livelihood security is by estimation on whether the nutritional and dietary needs are also sufficiently met (Wilkes *et al*., 2010). This is especially crucial in ensuring livelihood securities in the hilly regions of North-East India, where the indigenous inhabitant are dependent on the cultivation of bananas owing to high economic returns and lower labor input as compared to other crops in the region (Murry and Das, 2019). The nutritional composition of the fruit is reported to be determined by a combination of factors. These include the genetic constituent of the plants, the complex edaphic factors, farming practices, the stage of ripening and availability of nutrients and climatic trends (Baiyeri *et al*., 2011). One essential component of soil in relationship with fruit composition is reported to be soil N content. Shewry and Lookhart (2003) report that the proteins, namely glutenin and gliadin, significantly alter dough making capacity of the flour. In Nagaland, the practice of shifting cultivation has been practised since time immemorial. However, increased cropping cycle and reduction of fallow is reported to degrade soil quality. Therefore the introduction of banana cultivars under such degraded sites may negatively affect the nutrient composition of the fruit. This is because there is both physical degradation (erosion) and reduction in the organic matter, ultimately affecting nutrient content (Bünemann *et al*., 2018). To ensure the maximum economic return and livelihood security, a re-examination is needed on the effects of fallow on the proximate composition of the fruits. Zonfuo and Omuoru (1988) report that one way to improve the economic viability of bananas is by increasing the nutrient content in the fruits, especially the underutilized portion such as peels. Such increased nutrients make it a vital component in production of pastries, desserts and cream products owing to their resistant starch, fibre and polysaccharides (Emaga *et al*., 2007; Ng *et al*., 2014). Adeyemi and Oladiji (2009) also report on the role of ripening in determining the nutritional composition of banana. The workers highlight the variation in nutritional composition of banana in the unripe and ripe fruits. Such study highlights the different minerals and elements present at different stages allowing for efficient utilization. The present chapter

attempts to establish the relationship between the nutrient composition of fruits of banana under Jhum lands and fallow lands by recording the proximate composition of the two selected *Musa* cultivars at different ripening stages.

5.2 Results

5.2.1 Proximate composition of Aot Mungo

The result of the One-way ANOVA with post-hoc DMRT is displayed in **Table 10.1**. The F and P values recorded are presented at **Appendix III**. It is observed that the protein content varied significantly in the unripe peel (F=234.49, p=<0.001), ripe peel (F=105.15, p=<0.001), unripe pulp (F=9.18, p=0.006) and ripe pulp (F=7.60, p=0.010), respectively. The present study reports that protein content was highest at AJL12 and significantly decreased at JL. Highest protein was recorded at AJL12 in the ripe pulp (1.53%), while lowest was observed at site JL in the raw peel (0.52%). Moisture content did not vary significantly in the unripe peel (F=1.03, p=0.428) and ripe peel (F=1.224, p=0.362) content, but varied significantly in the unripe pulp (F=133.28, p=<0.001) and ripe pulp (F=11.60, p=0.003) among the sites. A similar trend of increased moisture content was observed at AJL12 as compared to no fallow or reduced fallow i.e., JL, AJL3 and AJLB. Highest moisture content was recorded at AJL12 in the ripe pulp with a value of 43.95 %, whereas lowest value was observed at AJLB with a value of 14.41 %. It is also observed that moisture content was higher in the ripe fruit components during the study period. Ash content also did not vary significantly between the sites in the unripe peel content (F=2.599, p=0.125), but varied significantly in the ripe peel (F=5.427, p=0.025), unripe pulp (F=6.617, p=0.015) and ripe pulp (F=6.217, p= 0.017), respectively. Similar trend of higher ash content was reported at AJL12 as compared to the other sites. Highest ash content was reported in raw peel (10.10%) at site AJL12, whereas lowest was reported in ripe pulp (2.43%) at JL. It is observed that ash content was significantly higher in the underutilized fruit component i.e. peel during the study period. Crude fibre did not vary significantly in the unripe peel content (F=2.59, p=0.125), but varied significantly in the ripe peel (F=5.42, p=0.025), unripe pulp (F=6.617, p=0.015) and ripe pulp (F=6.217, p=0.017), respectively. A significant reduction in crude fibre content was observed with introduction of fallow. Crude fibre was reported to be highest in the ripe pulp (33.70%) at JL, and lowest in raw pulp (1.73%) at AJL12. There was no significant variation in crude fat content in the unripe peel (F=2.874, P=0.103), ripe peel (F=2.021, p=0.190) and unripe

pulp (F=3.645, *p*=0.064), but significant variation was observed in the ripe pulp content (F=5.554, *p*=0.023). Crude fat content was lowest at JL (0.52%) in the ripe pulp content and highest at the AJL12 raw peel (6.37).

Lastly, a significant variation in total carbohydrates was reported in unripe peel (F=464.636, *p*=<0.001), ripe peel (f=516.58, *p*=<0.001), unripe pulp (F=46.29, *p*=<0.001), while no significant variation was reported in ripe pulp (F=0.433, *p*=0.735). The Pearson's correlation test report that ash content positively correlated with P levels (r=0.597), whereas protein content was significantly correlated with silt content during the study period (r=0.596) as shown in **Table 10.2**.

Table 10.1: Proximate composition of Aot Mungo from the study sites (% dry weight basis)

Plant part	Site	Protein(%)	Moisture(%)	Ash(%)	Crude fibre(%)	Crude Fat(%)	Total Carbohydrate(%)
Unp	JL	0.52±0.09a	14.87±0.65a	9.57±0.04ab	23.00±1.24b	5.80±0.04a	46.24±0.99b
Unp	AJL3	0.55±0.03a	15.84±1.42a	9.27±0.54a	23.57±0.37b	5.93±0.28ab	44.84±3.28a
Unp	AJLB	1.04±0.09b	14.41±0.55a	9.77±0.23ab	17.03±0.04a	6.10±0.14ab	51.65±0.84d
Unp	AJL12	1.08±0.04b	15.23±0.26a	10.10±0.16b	16.57±0.40a	6.37±0.24b	50.65±3.87c
Rip	JL	0.88±0.07a	25.13±3.38a	7.84±0.04a	33.70±0.21c	3.58±0.10a	28.87±1.21c
Rip	AJL3	0.88±0.001a	31.57±2.01a	8.03±0.05ab	32.03±0.81b	3.53±0.49a	23.95±0.90a
Rip	AJLB	1.05±0.47b	29.47±9.8a	8.37±0.32b	26.47±1.04a	3.57±0.61a	31.08±0.59d
Rip	AJL12	1.07±0.28b	35.10±0.94a	8.43±0.09b	25.87±.018a	4.37±0.12a	25.16±2.19b
Unpu	JL	1.03±0.02a	17.11±0.81a	6.17±0.04a	3.24±0.10b	1.07±0.04a	71.39±0.33c
Unpu	AJL3	1.05±0.03a	18.57±1.38a	7.29±0.70b	3.22±0.08b	1.30±0.35ab	68.58±11.04b
Unpu	AJLB	1.23±0.09b	38.66±1.07b	7.40±0.21b	1.90±0.08a	1.57±0.04b	49.26±0.94a
Unpu	AJL12	1.17±0.08b	36.92±2.06b	7.73±0.12b	1.73±0.38a	1.60±0.07b	50.85±0.33a
Ripu	JL	0.94±0.29a	35.70±2.82a	2.43±0.09a	2.87±0.75ab	0.52±0.02a	57.54±0.89a
Ripu	AJL3	1.15±0.03a	36.10±2.44a	3.10±0.13b	3.72±0.17b	0.63±0.35b	55.29±0.98a
Ripu	AJLB	1.52±0.01b	43.83±0.60b	3.14±0.11b	2.33±0.47a	0.63±0.04b	48.54±2.16a
Ripu	AJL12	1.53±0.04b	43.95±0.59b	3.20±0.35b	2.61±0.01a	0.64±0.03b	48.07±0.37a

Values are expressed as Mean ± standard deviation. Different alphabets in their respective column are significantly different at 5% level by Duncan's multiple range test (p=<0.05).

Table 10.2: Correlation matrix of the proximate composition of Aot Mungo with soil parameters

	Protein	Moisture	Ash	Fibre	Crude Fat	Total carbohydrate
pH	-0.578	-0.443	0.182	0.182	-0.024	0.169
EC	0.508	0.371	0.224	0.018	0.134	-0.38
SOC	0.538	0.319	0.173	-0.131	0.115	-0.196
N_{av}	0.475	0.144	0.398	-0.031	0.2	-0.201
K_{ex}	0.248	0.101	0.485	0	0.173	-0.203
P_{av}	0.244	0.100	**0.597***	0.228	0.4	-0.381
Moisture	0.588	0.407	0.155	-0.111	0.007	-0.263
BD	-0.571	-0.314	-0.253	0.003	-0.113	0.319
Clay	0.549	0.275	0.217	-0.161	0.11	-0.143
CEC	0.594	0.343	0.22	-0.13	0.03	-0.212
TN	0.267	0.104	0.275	-0.123	0.024	-0.061
sand	-0.409	-0.111	-0.152	0.253	0.117	-0.049
silt	**0.596***	0.351	-0.2	-0.412	-0.389	0.067

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

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

5.2.2 Proximate composition of Atsu Mungo

One-way ANOVA with post-hoc DMRT was implemented to test if there existed any significant variation in the different fruit content among the different sites (**Table 11.1**) The F and P values recorded are presented at **Appendix III**. Protein content did not vary significantly between sites in the unripe peel (F=0.459, *p*=0.718) and ripe peel (F=2.756, *p*=0.111), but varied significantly in the unripe pulp (F=8.090, *p*=0.008) and ripe pulp (F=5.930, *p*=0.020) among the varying sites. Protein content was highest in ripe pulp (1.22) at AJL12, whereas it was lowest in ripe peel at JL (0.54%). It is also observed that protein content was higher in the ripe fruit components as compared to the raw components. Moisture content did not vary significantly between the sites in the unripe peel (F=0.459, *p*=0.718), and ripe peel (F=2.767, *p*=0.111), but varied significantly in the unripe pulp (F=8.090, *p*=0.008) and ripe pulp (F=5.930, *p*=0.020), respectively. Moisture content displayed a similar trend, with highest value recorded at AJL12 in the ripe pulp (42.64%) and lowest in raw peel (15.17%) at JL. Higher moisture content in the ripe fruit component as compared to the raw component was also reported. Ash content varied between the sites in the unripe peel (F=7.141, *p*=0.012), ripe peel (F=113.38, *p*=<0.001), unripe pulp (F=4.237, *p*=0.001) and ripe pulp (F=14.75, *p*=0.001). Higher ash content was reported in the peel components as compared to the pulp components. The highest value of 8.71% was reported in the raw peel at AJL12, and lowest value of 1.87% was reported in ripe pulp at JL. Crude fibre content varied significantly between all the sites in the unripe peel (F=71.64, *p*=<0.001), ripe peel (F=14.79, *p*=0.001), unripe pulp (F=251.51, *p*=<0.001) and ripe pulp (F=37.22, *p*=<0.001), respectively. Highest value was reported at JL with a value of 23.73% in the ripe peel, while lowest value of 2.13% was reported in the raw pulp at AJL12. In the crude fat content, a similar observation is made with significant variation between all the sites, i.e. unripe peel (F=71.64, *p*=<0.001), ripe peel (F=14.79, *p*=0.001), unripe pulp (F=251.510, *p*=<0.001) and ripe pulp (F=37.22, *p*=<0.001), respectively. Significantly higher values of crude fat in the peel component was also reported. The highest values was reported in the raw peel with a value of 6.80% at AJL12, while lowest value of 0.64% was reported in the ripe pulp at JL. Total carbohydrates displayed no significant variation in the unripe peel (F=4.072, *p*=0.50) and Ripe pulp (F=3.12, *p*=0.088), but displayed a significant variation in the ripe peel (F=71.26, *p*=<0.001) and unripe pulp (F=71.26, *p*=<0.001) are observed respectively. The study also

observe positive correlation between ash content and K (r=0.514) and P (r=0.628) levels of soil (**Table 11.2**).

Table 11.1: Proximate composition of Atsu Mungo from the study sites (% dry weight basis)

Plant part	Site	Protein(%)	Moisture(%)	Ash(%)	Crude fibre(%)	Crude fat(%)	Total carbohydrate(%)
Unp	JL	0.54±0.01a	15.17±0.23a	7.35±0.03a	16.50±0.35b	6.25±0.46a	53.68±0.21b
Unp	AJL3	0.53±0.03a	16.50±0.43ab	7.80±0.45a	16.13±0.12b	6.43±0.18a	52.08±0.86ab
Unp	AJLB	0.65±0.01b	18.00±1.43bc	8.38±0.16b	14.00±0.04a	6.30±0.42a	52.04±0.64ab
Unp	AJL12	0.71±0.08b	18.53±0.54c	8.71±0.12b	13.27±0.37a	6.80±0.88a	51.39±0.91a
Rip	JL	0.72±0.03a	32.57±0.61a	7.14±0.08a	23.73±0.18c	2.37±0.24a	33.14±0.77c
Rip	AJL3	0.76±0.08a	33.50±0.40a	7.83±0.51a	22.04±1.45bc	3.03±0.04b	32.52±1.69c
Rip	AJLB	0.87±0.09b	36.60±0.35b	7.43±0.12a	21.43±0.41bc	3.08±0.10b	30.29±1.38b
Rip	AJL12	0.88±0.01b	41.17±0.62c	7.07±0.32a	18.57±0.41a	3.13±0.12b	28.84±2.01a
Unpu	JL	1.04±0.01a	16.07±0.65a	3.02±0.10a	4.40±0.08c	0.93±0.02a	75.04±1.97c
Unpu	AJL3	1.05±0.001a	16.37±0.44a	5.24±1.16b	2.17±0.09b	1.09±0.01b	74.60±0.38c
Unpu	AJLB	1.07±0.39a	17.16±0.10ab	7.23±0.12bc	2.40±0.14a	1.13±0.04b	71.37±0.03a
Unpu	AJL12	1.09±0.42a	17.61±0.55b	6.32±0.07c	2.13±0.04a	1.17±004b	72.11±0.86b
Ripu	JL	1.05±0.01a	33.40±0.99a	1.87±0.13a	4.48±0.08b	0.64±0.02a	58.74±1.65b
Ripu	AJL3	1.06±0.001ab	38.70±1.83b	2.22±0.08ab	4.17±0.16b	0.67±0.09a	53.35±0.12ab
Ripu	AJLB	1.16±0.008ab	39.93±0.84bc	2.23±1.88ab	3.24±0.15a	0.80±0.01b	53.06±0.52ab
Ripu	AJL12	1.22±0.07c	42.64±1.75c	2.30±0.18b	3.07±0.20a	0.83±0.03b	50.40±2.17a

Values expressed as Mean ± standard deviation. Different alphabets in their respective are significantly different at 5% level by Duncan's multiple range test (p=<0.05).

Table 11.2: Correlation matrix of the proximate composition of Atsu Mungo with soil parameters

	Protein	Moisture	Ash	Fibre	Crude Fat	Total carbohydrate
pH	-0.23	-0.419	0.082	0.169	-0.087	0.208
EC	0.224	0.211	0.329	0.018	0.083	-0.227
SOC	0.218	0.151	0.245	-0.124	0.092	-0.098
N_{av}	0.164	-0.089	0.447	-0.015	0.139	-0.026
K_{ex}	0.108	-0.212	0.514*	0.012	0.071	0.047
P_{av}	0.294	-0.104	0.628**	0.221	0.315	-0.198
Moisture	0.095	0.197	0.212	-0.1	-0.054	-0.113
BD	-0.17	-0.138	-0.36	0.001	-0.051	0.166
Clay	0.132	0.057	0.269	-0.156	0.091	-0.017
CEC	0.046	0.071	0.274	-0.116	-0.024	-0.03
TN	0.126	0.102	0.274	-0.123	0.027	-0.059
sand	0.007	-0.111	-0.152	0.253	0.114	-0.048
silt	0.371	0.185	0.459	0.113	0.14	0.808

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

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

5.3 DISCUSSION

Proximate composition of *Musa* cultivars

The present study report that protein, moisture, and fiber increased with ripening in both *Musa* cultivars. There was also a decrease in the ash, fat, and carbohydrate content as the fruit ripened. The effect of the ripening process on the proximate content of the *Musa* cultivar is widely reported. Workers (Iliyasu and Ayo-Omogie, 2019; Ayodele *et al*., 2019) similarly report an increase in moisture, protein, and fiber with ripening, while there was a significant decrease in carbohydrate, lipid, and ash content in ripe and unripe fruit of *Musa* cultivars. Such information may be utilized for efficient extraction of the desired fruit component at different stages (Adeyemi and Oladiji, 2009). The site-wise comparison of the proximate contents of the *Musa* fruits displays a general trend of higher protein, moisture, ash, and fat content at AJLB and AJL12 as compared to JL and AJL3. The highest was reported at AJL12, which had the longest fallow period. Montgomery and Biklé (2021) similarly conclude that farming systems significantly alter nutrient contents in the crop. They report higher phytochemicals, especially compounds such as antioxidants and anti-inflammatory, in farming systems that employ organic cropping compared to conventional cropping. The increase in protein can be linked to an increase in the minerals and organic matter levels. An increase in nitrogen levels has been attributed to increased protein content in crops (Wang *et al*., 2007) and increased organic matter (Wood and Baudron, 2018). Soils at JL and AJL3 possessed lowered conductivity, SOC, moisture, and CEC (**Tables 9.1** and **9.2**). Likewise, Wilkes *et al.* (2010) conclude that soil type impacts the protein content of fruits. They report that soil with higher clay and strong structure (vertosol) produced higher protein content when compared to low clay (kandosol soils). An increase in yield, weight, and size of fruit is also attributed to the increased moisture content in the soil (Sharma *et al.*, 2018). The reduced moisture content at JL may be one reason for the decreased moisture in the fruits at these sites. A rise in soil nutrients may also explain the increased fat content at AJLB and AJL12. Shanmughavel and Kazibwe (2001) also report on the beneficial aspect of intercropping of crops with bamboo to increase yield. The elevated nutrient content at AJLB may also be attributed to the role of bamboo in restoring soil by means of increased nutrient mineralization, decreased BD, improved microbial biomass, higher SOC and higher moisture retention (Arunachalam and Arunachalam, 2002; Mishra *et al*., 2014; Shilla and Mir, 2017; Shia *et al*., (2017).

The present findings also reports that the ash content of the Aot Mungo was positively correlated with P (**Table 10.2**). Likewise, a positive correlation of ash content of the Atsu Mungo with K and P (**Table 11.2**) was reported. The relationship between soil, moisture, nutrients, and fertilizers has been well documented (Aroszewska, 2011). Potassium (K) contributes as much as 50% of the total ash content in plants and is among the essential elements for plants (Kuzin and Solovchenko, 2021). The higher ash content in the peel during the present study also highlights the potential source of minerals in the underutilized peel component. Similar reports on the increased ash content in peel have been reported by Oyeyinka and Afolayan (2019). Our work is also supported by workers (Mohamed *et al*., 2018; Qiu *et al*., 2018) who similarly concluded that P and K significantly affected yield and quality. Silt content was also reported to be positively correlated with protein. Kim *et al.* (2015) similarly report on the positive association of silt contents with regards to fruit quality and production. The relationship between soil quality and the quality and quality of fruits is widely reported (Mi *et al*., 2018; Basak and Gajbhiye 2018; Wang *et al.*, 2019).

5.4 SUMMARY AND CONCLUSION

The study on the proximate composition of the two selected *Musa* cultivars under Jhum and fallow land provide insight into the relationship between soil and nutrient composition in Mokokchung district, Nagaland. From the result of the proximate composition of Aot Mungo, the present study reports that fallow significantly affects the proximate composition of the fruit. The present study reports increased protein content at a higher fallow period (AJL12) and lower protein at JL. Similarly, moisture content was observed to be highest at AJL12 as compared to no fallow or reduced fallow, i.e., JL, AJL3 and AJLB. The Ash highest ash content was reported to be highest in raw peel (10.10%), highlighting the high nutrient potential of the underutilized fruit component, i.e., peel. A significant reduction in crude fibre content was observed with the introduction of fallow. Crude fat content was lowest at JL (0.52%) in the ripe pulp and highest at AJL12 in the raw peel (6.37%). The implementation of Pearson's correlation test also displays the relationship between ash content and P levels and the relationship between silt and protein content. A similar observation was reported for cultivar Atsu Mungo. Protein content was highest at AJL12 and lowest at JL (0.54%). Moisture content displayed a similar trend with highest value at AJL12 and lowest at JL. Higher ash content was also reported under the

peel components as compared to the pulp components, highlighting the high mineral content under the cultivar. Similar variation in Crude fibre, crude fat and total carbohydrates, was observed. The study also report on the positive relationship between ash content and K and P levels for Atsu Mungo. The information from the present study report on the significant role of soil in determining the nutrient composition of the cultivars. Therefore this result is in agreement with our third hypothesis "Shifting cultivation and fallow length alter the proximate composition of *Musa* cultivars." The negative aspect of unsustainable means of farming (reduced fallow and increased cropping cycle) should therefore be thoroughly disseminated to the local stakeholders.

CHAPTER-6

EFFECT OF DIFFERENT FALLOW ON RHIZOSPHERIC FUNGAL DIVERSITY

6.1 INTRODUCTION

Fungi are grouped as "secondary consumers" and are vital for the various decomposition process in soil (Miah *et al*., 2010). Despite the beneficial aspect of both bacteria and fungi in soil, it is reported that owing to the extensive hyphae network and increased diameters of the network, fungi by far possess the highest biomass in soil (Killham, 1994). The presence of such fungi in the soil increases the symbiotic relationship between plants and microbes. This symbiosis led to increased tolerance, increased soil buffering capacity, protection from pathogens, stress tolerance, and increased productivity (Jackson and Mason, 1984). However, owing to the reports of unsustainable practices of shifting cultivation in the present study area, its impact on the fungal population in the rhizosphere region must be monitored. Some of the problems of anthropogenic disturbances, such as excessive use of salt, burning, tillage and fertilizers, may negatively affect the fungal population by reducing diversity, richness and evenness, leading to a reduction in mutualistic fungi (Egerton-Warburton and Allen, 2000; Corkidi *et al*., 2002). Such alteration of the microbial population ultimately determines the nutrient mineralization rate, stress tolerance and crop-microbe symbiosis, affecting the productivity of crops (Montgomery and Biklé, 2021). There is also the practice of the increased cropping cycle and monoculture of cash crops in Jhum lands of Nagaland (Temjen *et al*., 2022). This led to an increased abundance of a particular microbe based on the singular crop available at the site. Such changes are reported to increase the pathogenic effects of fungi (Hendrix *et al*., 1986). Soil abiotic traits such as pH, nutrients, soil texture, and organic matter are also reported to significantly influence the pathogenic effect of certain fungi. Orr and Nelson (2018) report on the negative relationship between organic matter and nutrient content on the severity of pathogenic effect of Fusarium wilt caused by *Fusarium oxysporium*. Therefore adequate information on the soil properties is required to manage or reduce the severity of pathogenic effects (Lemanceau, 1989). Biodiversity indices such as Simpson's index, Pielou's evenness, and others have been utilized by workers to estimate the fungal diversity of rhizospheric fungal diversity (Salve *et al*., 2019). Such information aid in the inventory of the fungal population under different land

use. Tools such as Canonical Correspondence Analysis (CCA) are widely employed to explore the relationship between soil variables and fungal populations (Liu *et al*., 2016; Marín *et al*., 2017). Phosphate solubilizing fungi (PSF) are strains of fungi with the capacity to solubilize insoluble phosphate (P), thereby increasing the P levels in the soil (Nahas, 1996). Although P is essential for plant growth, plants utilize a trace amount of P present in the soil. This leads to increased dependence on chemical P by crops which eventually leads to soil degradation. The presence of such biological PSF would therefore be beneficial for both the economy as well as its environment (Whitelaw, 2000). This is crucial in the region, as banana production forms a substantial form of livelihood security for the local stakeholders under Mokokchung, Nagaland. Therefore, the chapter attempts to isolate the fungal population present in the *Musa* cultivars' rhizosphere region at the different fallow lands. The study also attempts to observe the seasonal variation in diversity and PSF in the study sites. The study will raise awareness of fungal's spatial and temporal variation in relation to *Musa* cultivars. The data collected will be valuable to researchers and stakeholders for the proper managements of the microbial population.

6.2 RESULTS

6.2.1 Fungal species isolated from the study sites

A total of 36 fungal species were isolated from rhizospheric soils of *Musa* cultivars during the present study (**Table 12**). The descriptors of the fungal culture is presented at **Appendix IV** They were: *Absidia* sp., *Acremonium murorum, Acremonium strictum, Aspergillus candidus, Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger*, *Aspergillus* sp. 1, *Aspergillus* sp. 2, *Aspergillus versicolor, Chaetomium* sp., *Chladosporium chaldosporiodes, Cladosporium oxysporum, Eupenicillium javanicum*, *Fusarium* sp. 1, *Fusarium* sp. 2, *Geotrichum candidum,Humicola* sp., *Mortierella* sp., *Mucor circinelloides*, *Mucorhiemalis, Mucor* sp. 1, *Paecilomyces carneus,Paecilomyces farinosus*, *Penicillium brevicompactum, Penicillium citrinum, Penicillium digitatum, Penicillium* sp. 1, *Penicillium* sp. 2, *Penicillium* sp. 3, *Penicillium* sp. 4, *Rhizopus* sp., *Scopulariopsis* sp., *Trichoderma harzianum, Trichoderma viridie* and *Trichophyton* sp. (**Fig. 10.1** and **Fig. 10.2**). The highest occurrence of genera during the study period belonged to *Aspergillus* spp. and *Penicillium* spp. The percentage contribution of the fungal population form the study sites are presented in **Appendix V**. At site JL, a total of 19 fungal species were reported under the rhizosphere region of *Musa* cultivars.

Penicillium sp. 1 and *Aspergillus* sp. 1 had the highest percentage contribution (10.50%), and lowest contribution was recorded belonging to *Absidia* sp. (0.72%) and *Fusarium* sp. 1 (0.36%) as shown in **Fig. 11.1**. At site AJL3, the total fungal diversity was recorded as 25. Highest percentage contribution was recorded by *Penicillium citrinum* (11.63%) and lowest by *Fusarium* sp. (0.314%) and *Penicillium* sp. 1 (0.94%) as shown in **Fig. 11.2**. At AJLB, a total of 30 fungal species were isolated. Highest percentage contribution was recorded belonging to *Penicillium* sp. 4 (8.88%) and lower values were recorded belonging to *Aspergillus candidus*, *Aspergillus versicolor*, *Fusarium* sp. 1, *Penicillium* sp. 4 (0.95%) as shown in **Fig. 11.3**. At AJL12, a total of 32 fungal diversity was recorded. Highest percentage contribution was recorded belonging to *Aspergillus flavus* (5.54%) and *Aspergillus niger* (5.54%), and lowest was recorded by *Mucor* sp. 1 (0.79%) and *Humicola* sp. (0.52%) as shown in **Fig. 11.4**.

Table 12: Rhizospheric fungal diversity of *Musa* cultivars from the four study sites

Fungal species	SITES			
	JL	**AJL3**	**AJLB**	**AJL12**
Absidia sp. ****	P	P	P	P
Acremonium murorum ***		P	P	P
Acremonium strictum ***		P	P	P
Aspergillus candidus ***	P		P	P
Aspergillus flavus ****	P	P	P	P
Aspergillus fumigatus ****	P	P	P	P
Aspergillus niger ****	P	P	P	P
Aspergillus sp. 1 ***	P	P		P
Aspergillus sp. 2 ***	P	P	P	
Aspergillus versicolor **			P	P
Chaetomium sp. ***		P	P	P
Chladosporium chaldosporiodes ***	P	P		P
Cladosporium oxysporum *				P
Eupenicillium javanicum ****	P	P	P	P
Fusarium sp. 1***	P	P	P	
Fusarium sp. 2 *	P			
Geotrichum candidum ***		P	P	P
Humicola sp. ***		P	P	P
Mortierella sp. ***	P		P	P
Mucor circinelloides ****	P	P	P	P
Mucor hiemalis *		P		
Mucor sp. 1 **			P	P
Paecilomyces carneus ****	P	P	P	P
paecilomyces farinosus ***		P	P	P
Penicillium brevicompactum **		P		P
Penicillium citrinum ***		P	P	P
Penicillium digitatum **			P	P
Penicillium sp. 1 ****	P	P	P	P
Penicillium sp. 2 ****	P	P	P	P
Penicillium sp. 3 ***	P		P	P
Penicillium sp. 4 **			P	P
Rhizopus sp. ****	P	P	P	P
Scopulariopsis sp. ***		P	P	P
*Trichoderma harianum****	P	P	P	P
Trichoderma viridie **			P	P
Trichophyton sp. **			P	P

Notes: P= present, *=Rare, **=not very common ***=Common ****=Very common

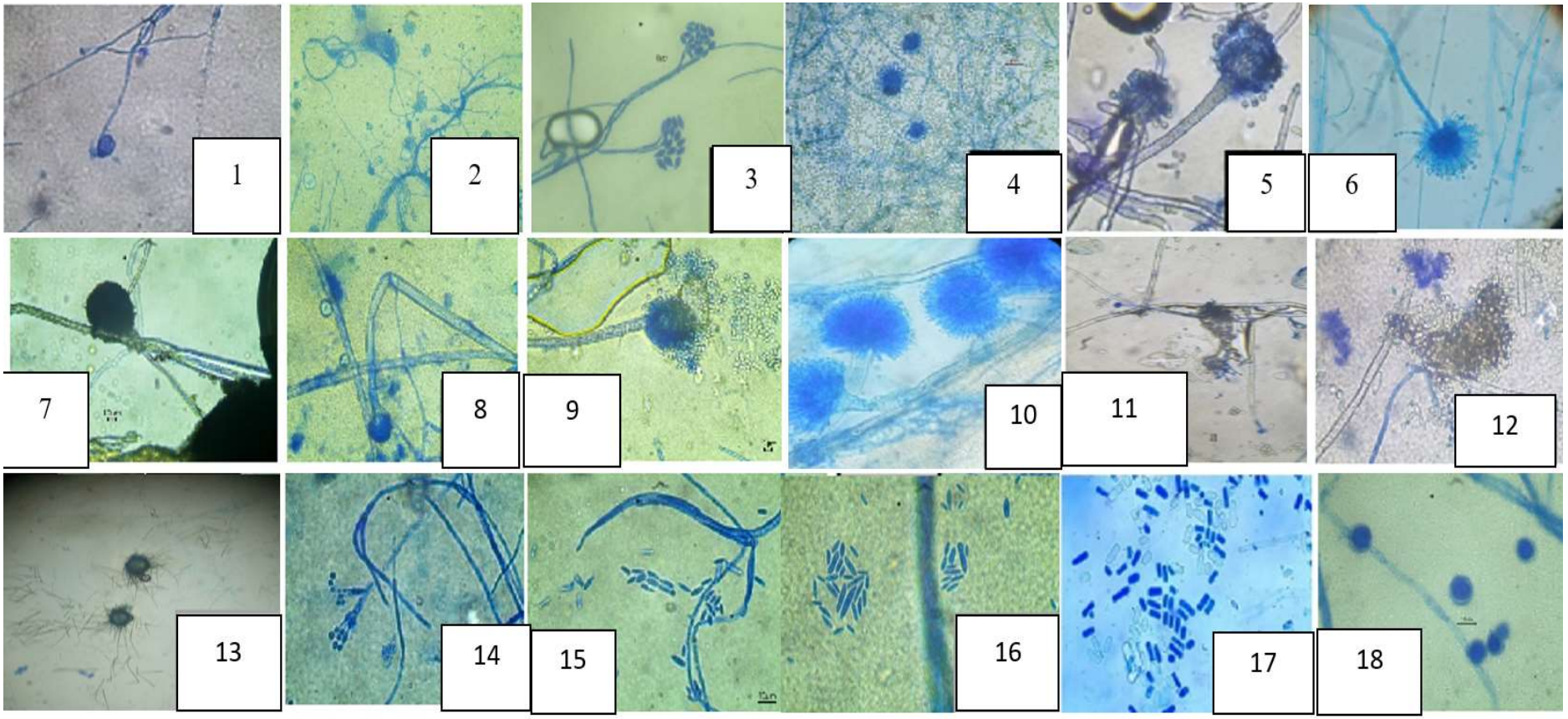

Fig 10.1: Microscopic view of isolated fungal species: **1:** *Absidia* sp. **2***:* *Acremonium murorum* **3:** *Acremonium strictum* **4:** *Aspergillus candidus* **5:** *Aspergillus flavus* **6:** *Aspergillus fumigatus* **7:** *Aspergillus niger* **8:** *Aspergillus* sp. 1 **9:** *Aspergillus* sp. 2 **10:** *Aspergillus versicolor* **11:** *Chaetomium* sp. **12:** *Chladosporium chaldosporiodes* **13:** *Cladosporium oxysporum* **14:** *Eupenicillium javanicum* **15:** *Fusarium* sp. 1 **16:** *Fusarium* sp. 2 1**7:** *Geotrichum candidum* **18***:* *Humicola* sp. Under 40x, scale bar=10 µm

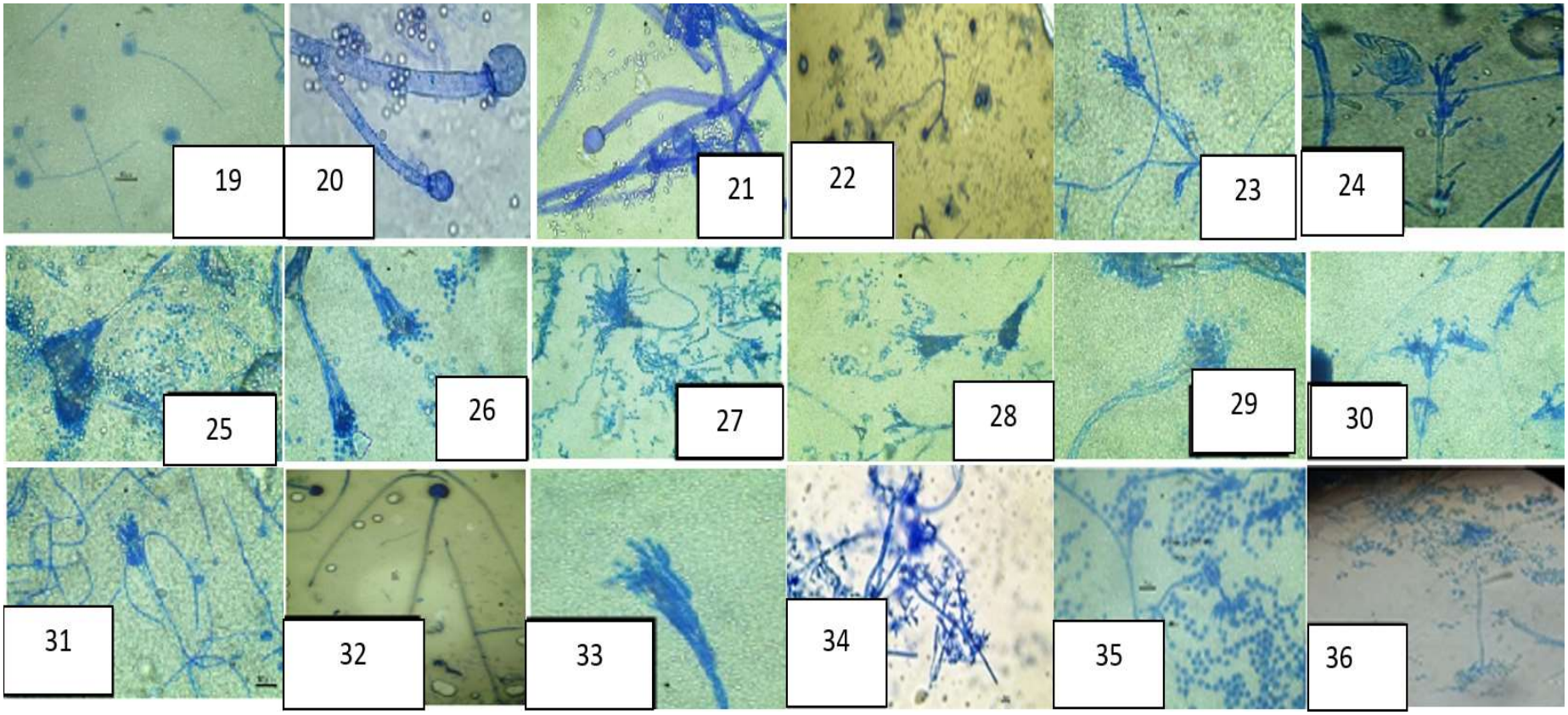

Fig 10.2: Microscopic view of isolated fungal species: **19:** *Mortierella* sp **20:** *Mucor circinelloides* **21:** *Mucor hiemalis* **22:** *Mucor* sp. 1 **23:** *Paecilomyces carneus* **24:** *Paecilomyces farinosus* **25:** *Penicillium brevicompactum* **26:** *Penicillium citrinum* **27:** *Penicillium digitatum* **28:** *Penicillium* sp. 1 **29:** *Penicillium* sp 2 **30:** *Penicillium* sp. 3 **31**: *Penicillium* sp. 4 **32:** *Rhizopus* sp. **33:** *Scopulariopsis* sp. **34:** *Trichoderma harzianum* **35:** *Trichoderma viridie* **36:** *Trichophyton* sp. Under 40x, scale bar=10 µm

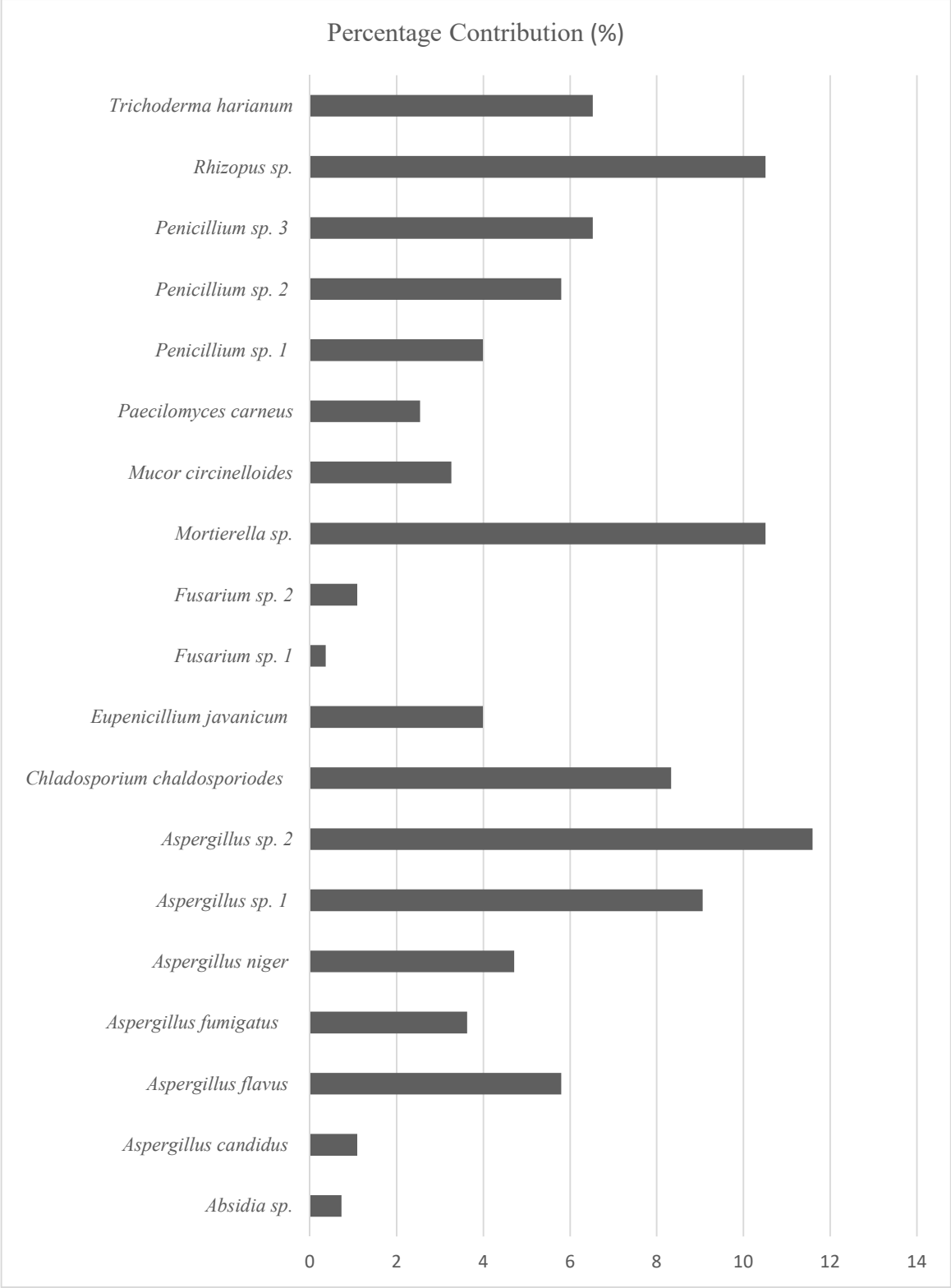

Fig 11.1 Percentage contribution of fungal diversity from site JL

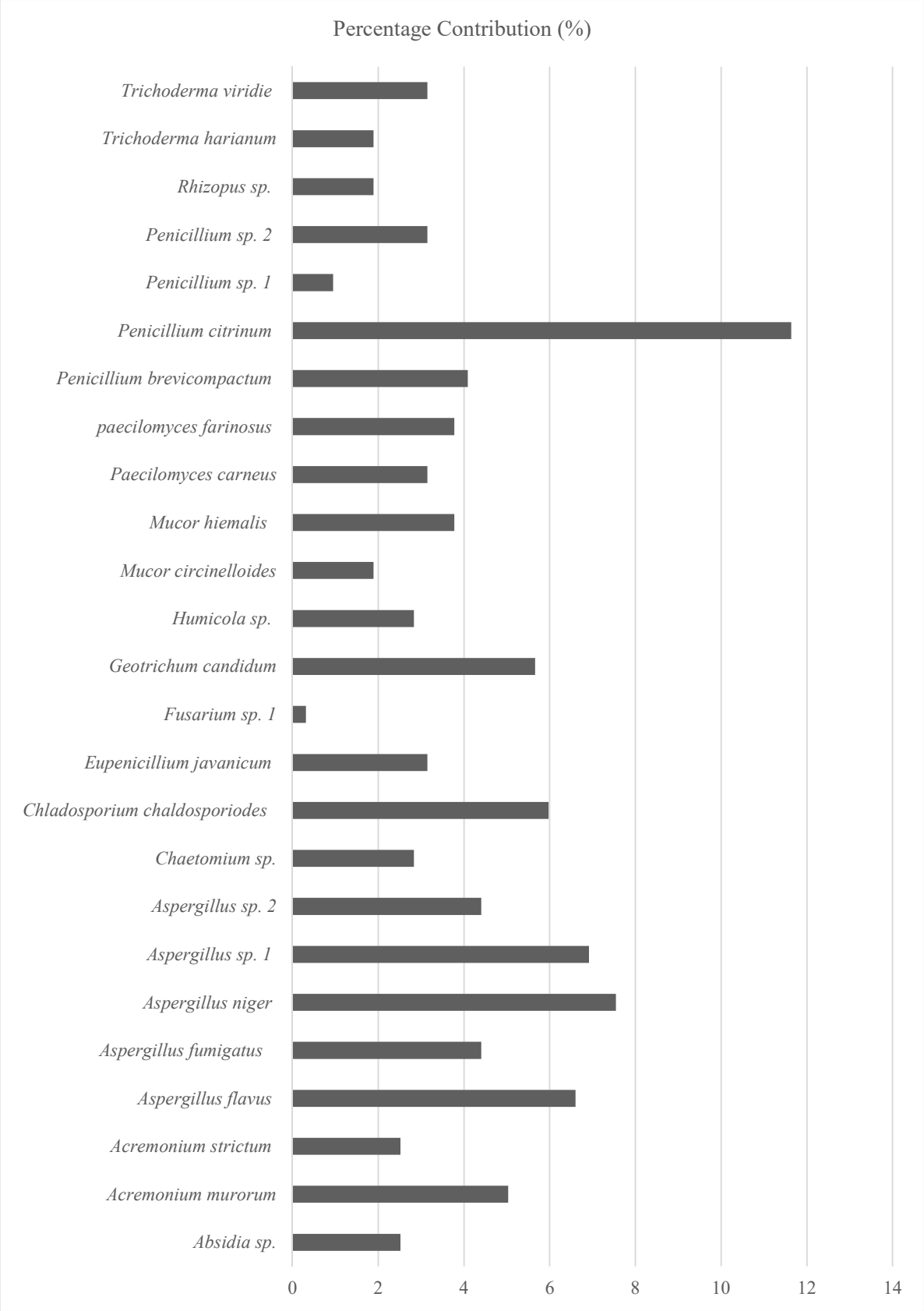

Fig.11.2: Percentage contribution of fungal diversity from site AJL3

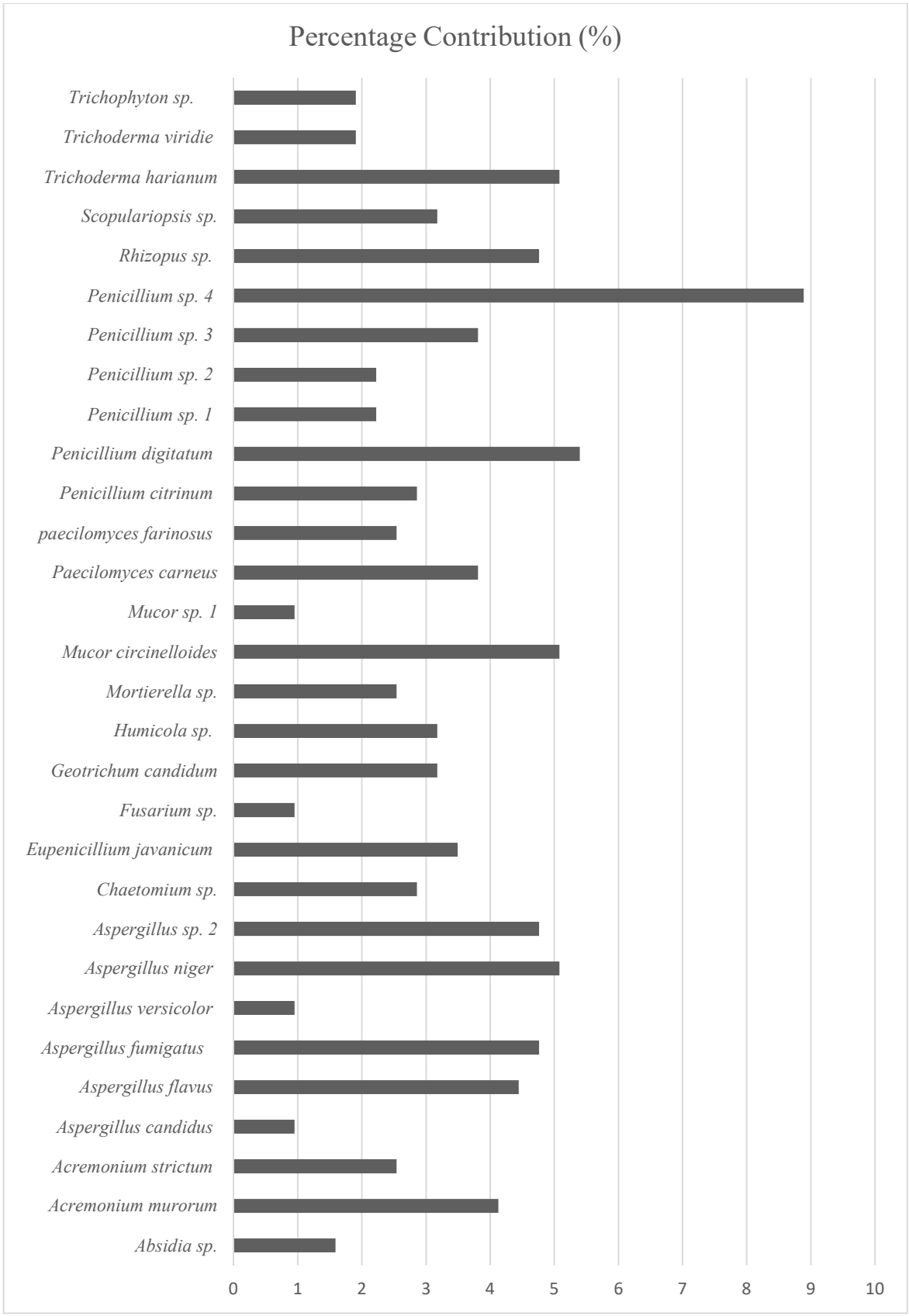

Fig.11.3: Percentage contribution of fungal diversity from site AJLB

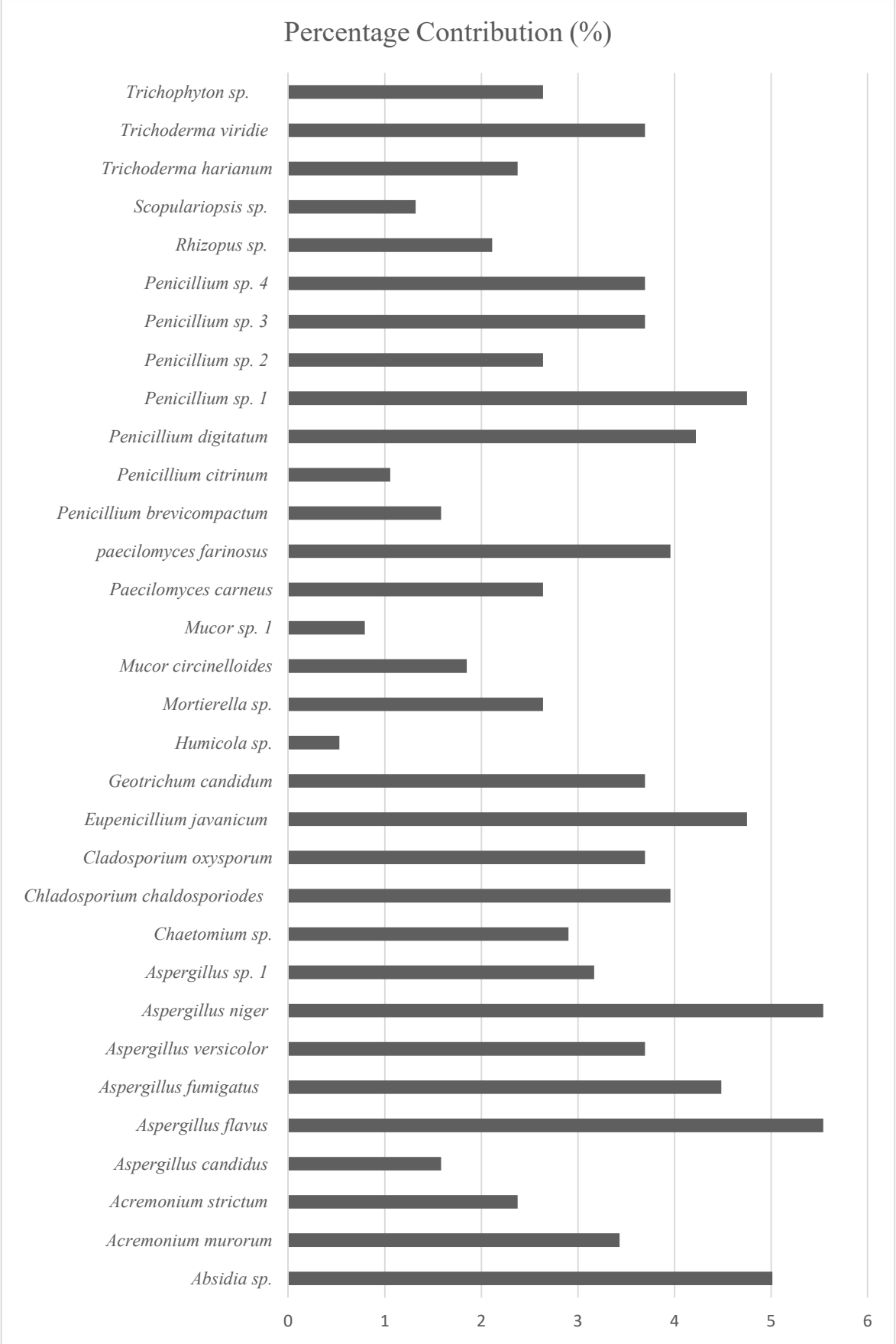

Fig.11.4: Percentage contribution of fungal diversity from site AJ12

6.2.2 Diversity indices

The result of the indices are presented in **Appendix VI**. Highest number of taxa (S) in the decreasing trend order were: AJL12 (32)>AJLB(30)>AJL3(25)>JL(19) was reported in the present study (**Fig. 12.1**). Similarly, higher individuals were recorded at AJL12 (379), followed by AJLB (315), AJL3 (318) and JL (276), respectively. The Simpons index of diversity was highest at AJL12 with a value of 0.96, followed by AJLB (0.95), AJL3 (0.94) and lowest at JL (0.92) as shown in **Fig. 12.2**. Maximum evenness value was recorded at AJL12 (0.90), followed by AJLB (0.87), AJL3 (0.84) and JL (0.77) as shown in **Fig.12.3**. Lastly, the Berger-Parker index value was highest at JL (0.118) followed by AJL3 (0.116), AJLB (0.089) and lowest at AJL12 (0.055), respectively during the study period (**Fig. 12.4**).

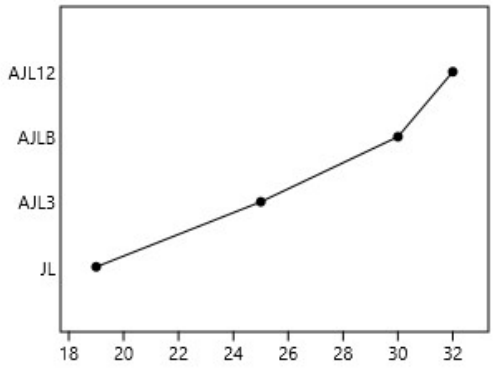

Fig.12.1: No of Taxa (S) from the study sites

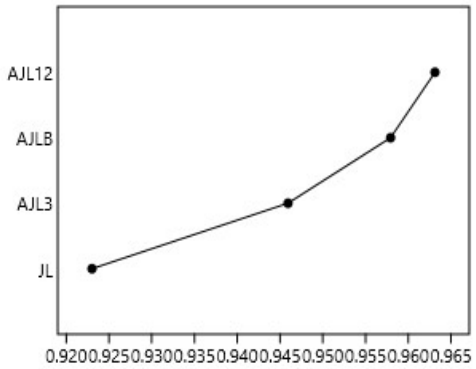

Fig.12.2: Simpons index of diversity

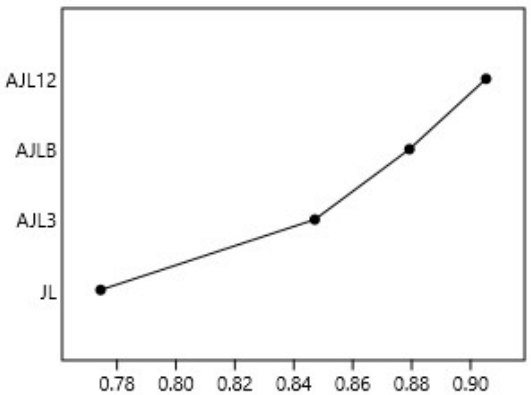

Fig.12.3: Pielou evenness index

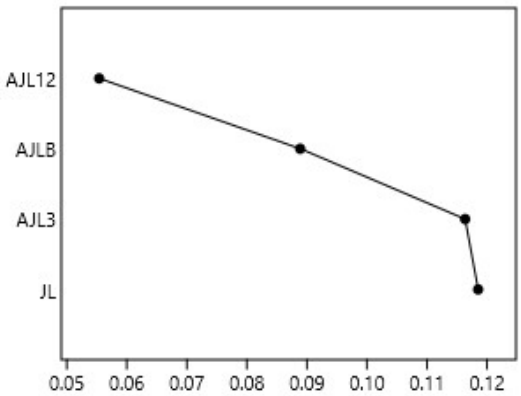

Fig.12.4: Berger parker index

6.2.3 Canonical correspondence analysis

The results of the CCA are depicted in **Fig. 13.1**, **13.2**, **13.3** and **13.4** respectively. Eigenvalue and Percentage Variance obtained from the Canonical correspondence analysis are presented at **Appendix VII**. At JL, maximum fungal diversity was reported during the autumn, summer and spring, and least diversity during winter. Among the soil variable, the present findings indicate that clay content, TN and BD, strongly influenced the fungal diversity. The first and second axis explain 53.34% and 32.74% of the variance. At AJL3, higher fungal diversity was observed during autumn, summer and spring, while lower diversity was observed during winter. It was observed that soil variables SOC, BD, clay, pH, available potassium and available nitrogen strongly influenced fungal diversity at AJL3. The first and second axis explain 64.06% and 21.95% of the variance.A similar trend was reported at AJLB with maximum fungal diversity during the autumn, summer and spring, and least diversity during winter. The present study revealed that BD, silt content, clay, pH, available potassium, available Nitrogen, Total Nitrogen, SOC, temperature and silt content influenced the fungal diversity at AJLB. The first and second axis explain 52.32% and 31.45% of the variance. Lastly at AJL12, a similar trend of fungal diversity in the order autumn>summer>spring> winter was observed during the study period. Soil factors such as SOC, moisture, available potassium, sand and clay content, pH, CEC, available Nitrogen, TN, temperature and BD influenced the fungal diversity. The first and second axis explain 49.53% and 30.96% of the variance.

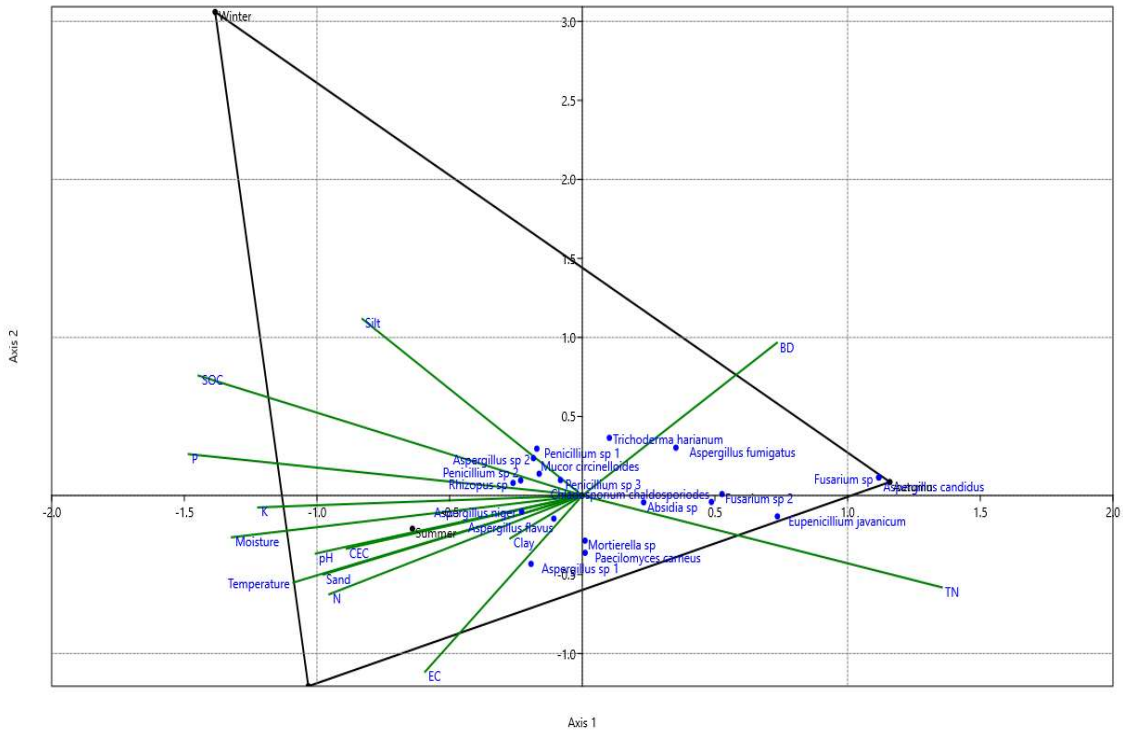

Fig. 13.1: CCA plot (Type 2 scaling) of fungi and soil variable at Site JL. Points represents different fungal species and soil variable are indicated by arrows.

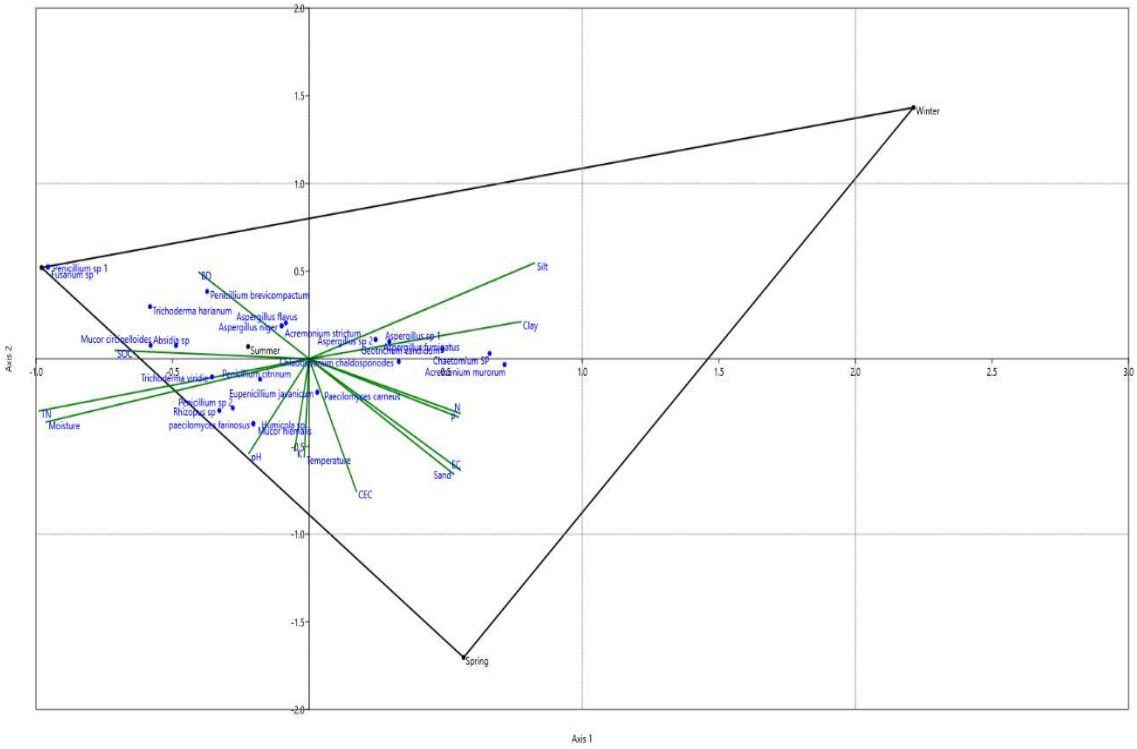

Fig. 13.2: CCA plot (Type 2 scaling) of fungi and soil variable at Site AJL3. Points represents different fungal species and soil variable are indicated by arrows.

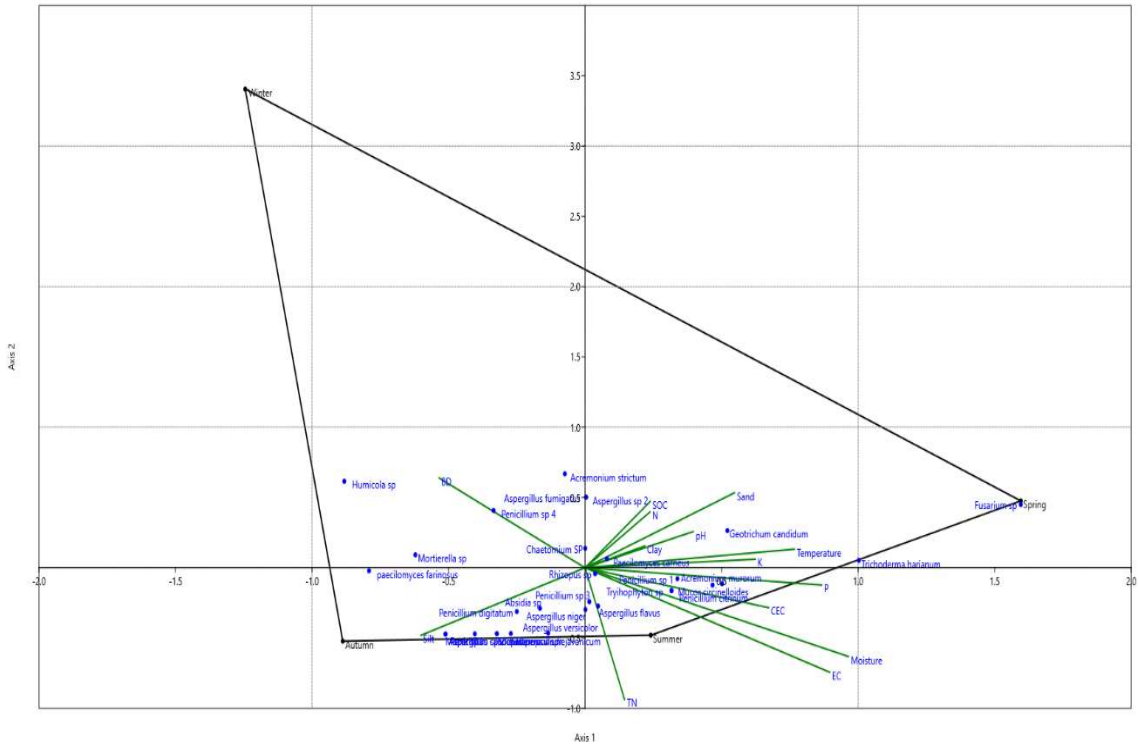

Fig. 13.3: CCA plot (Type 2 scaling) of fungi and soil variable at Site AJLB. Points represents different fungal species and soil variable are indicated by arrows.

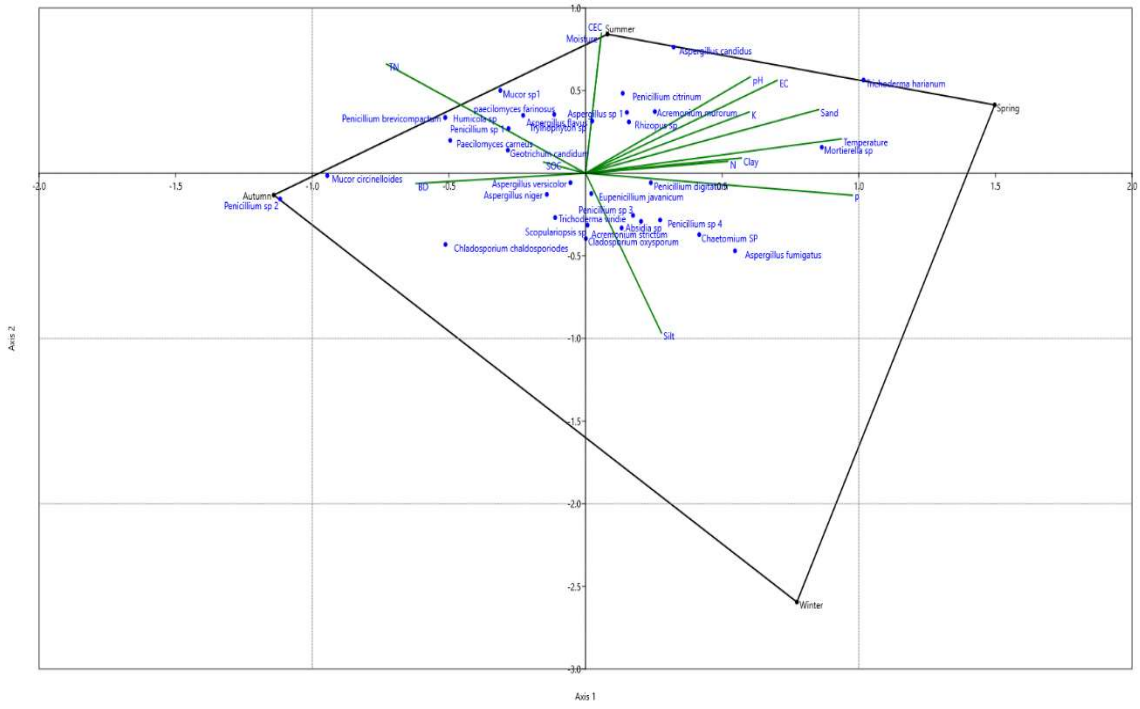

Fig. 13.4: CCA plot (Type 2 scaling) of fungi and soil variable at Site AJL12. Points represents different fungal species and soil variable are indicated by arrows.

6.2.4 Phosphate solubilizing fungi (PSF)

A total of 8 fungal isolates with the capacity to solubilize phosphate were isolated (**Plate VI**). The site wise presence of the PSF are depicted in **Table 13**. The present study also reports on the lowest number of PSF at site JL (5), followed by AJL3 (6). Site AJLB and AJL12 possessed the maximum number of PSF (7) during the study period. Higher number of PSF were reported belonging to genera *Penicillium* (3) and *Aspergillus* (2). There were 3 other genera that contributed to the PSF at the study sites, *viz*., *Acremonium murorum* (1), *Mucor* sp.1 (1) and *Rhizopus* sp. (1) respectively. Maximum solubilizing index (SI) was recorded by *Penicillium* sp. 4 (3.51 cm) and followed by *Penicillium* sp 1 (2.9 cm). Minimum SI was recorded belonging to *Aspergillus* sp. 1 (1.5cm) as shown in **Fig. 14**.

PLATE VI: Pikovskaya agar media containing phosphate solubilizing fungal isolates displaying clearing zone diameter/ Halo zone for estimation of Solubilization index.

Table 13: PSF screened from the study sites during study period

Sl no	PSF	JL	AJL3	AJLB	AJL12
1	*Acremonium murorum*		*	*	*
2	*Aspergillus* sp. 1	*	*		*
3	*Aspergillus niger*	*	*	*	
4	*Mucor* sp. 1			*	*
5	*Penicillium* sp. 1	*	*	*	*
6	*Penicillium* sp. 2	*	*	*	*
7	*Penicillium* sp. 4			*	*
8	*Rhizopus* sp.	*	*	*	*

*= Present

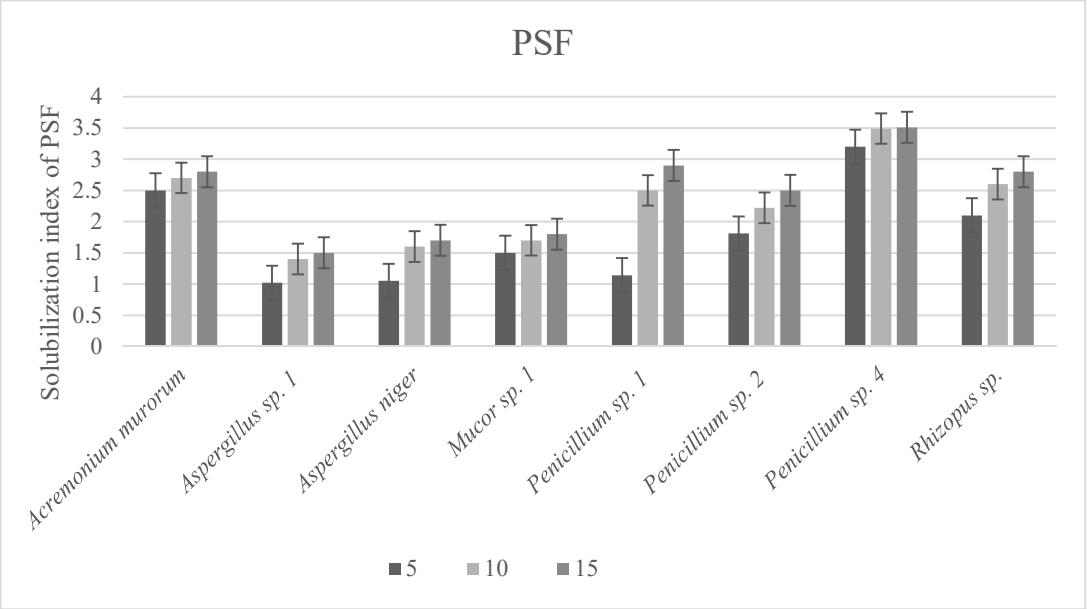

Fig. 14: Phosphate solubilizing index of fungal isolates under day 5, 10 and 15th

6.3 DISCUSSION

In the present study, the lowest fungal diversity from the soils of the rhizosphere region of *Musa* cultivars was observed at JL (19). With the introduction of fallow and vegetation, the fungal diversity increased in the order AJL3<AJLB<AJL12. This is also reflected in the decreased Simpson's index at JL and increased value at AJL3, AJLB and AJL12 (**Fig. 12.2**). This reduction in fungal diversity may be due to the anthropogenic activities at site JL. The disturbances include burning practices associated with Jhumming and monoculture farming activities which lead to decreased vegetation and litter input

(Serrasolsas and Khanna, 1995; Beschta *et al*., 2004). The practice of burning in particular make the Jhum soil lose the fungal community sensitive to elevated soil temperatures. Similar results were observed by Miah *et al*. (2010) who reported lowered fungal population in shifting cultivation sites as compared to forest areas. The study also report the highest genera from all study sites belonging to two genera i.e. *Aspergillus* and *Penicillium*. Perrone *et al*. (2011) reported that species that produce spore-bearing structures can be easier to discover. Fungal colony with good sporulating features has also been reported to colonize better on the culture plates (Jena *et al*., 2015). Therefore, fungal communities with lower CFU may likely be due to decreased spore production during the present study period. In contrast, Strobel *et al*. (2002) opined that higher CFU is mainly because of the anti-mycotic traits of the dominating genera. Therefore, the decreased fungal CFU of the other genera may also be due to the antimycotic traits of the dominating genera in the present study. The effects of shifting cultivation and fallow is also observed to determine the evenness of the fungal population. The present study reports on the lowered evenness at JL (0.774) compared to the fallow lands (**Fig. 12.3**). The fungal communities that can adapt to regular anthropogenic disturbances dominate the areas. This is also indicated in the elevated levels of Berger-Parker index (0.118) as shown in **Fig. 12.4**. The higher values of the Berger-Parker index in JL indicate that the most common species dominate the site. Similar reports on the adverse effects of shifting cultivation on the fungal diversity has been reported by workers (Garcia-Oliva *et al*., 1999; Beschta *et al*., 2004; Miah *et al*., 2010). Such reduction in the fungal population negatively affects soil quality by decreasing nutrients and ion mobility, nutrient availability and mineralization (Gazey *et al*., 2004; Miah *et al*., 2010). Unsustainable soil management may not only lead to reduction but also the disappearance of particular species for a significant period of time (Giardina *et al*., 2000). The present study also report greater *Fusarium* spp. at site JL as compared to the other sites. One reason for this may be the reduced soil quality and organic matter at JL (Orr and Nelson, 2018). Therefore, monocropping and reduced cropping cycles that degrade soil of its organic matter and favor specific fungal populations may display more pathogenic effects exhibited by the particular fungal strain. (Hendrix *et al*., 1986). The study also highlights the increased fungal diversity at AJLB. This may be because of the increased litter input, organic matter and SOC from the bamboo supplemented fallow. The increased carbon capturing under bamboo soils is reported to increase fungal diversity by producing fine roots (Lipson *et al*., 2014).

The present study also reports on the temporal variation of the fungal communities with the variation in season, depicted in the CCA plot (**Fig. 13.1**, **13.2**, **13.3** and **13.4**). It is reported that seasonal variables such as temperature and precipitation significantly determine the fungal population (Smilanick and Mansour, 2007). A general trend was reported in the present study, where lower fungal diversities were observed during the colder season. In contrast, higher fungal diversity was reported during the warmer season. The higher fungal population during the warmer season in the order spring<summer<autumn in the present study may be due to the increased litter input during the warmer periods. Sadaka and Ponge (2003) report that increased litter fall alters the fungal community. Whereas the decreased fungal diversity during winter may be attributed to the decreased nutrient input, decreased moisture availability and colder temperature determining the soil quality. Shigyo *et al*. (2019) similarly report on the significant role of soil fertility in determining the season variation of microbial population, abundance, diversity and size. The result of the CCA plots also displays the role of the soil variables in determining the fungal population at the study sites. Berg *et al.* (1998) report on the significant role of soil variables, especially moisture content and soil temperature, in determining soil fungal diversity. The present findings are also supported by Siles *et al*. (2017), who report on the significant role of soil organic matter in determining fungal diversity. Likewise, Shigyo *et al*. (2019) report on the significant role of K and P in influencing the diversity of soil fungal population. The present study also highlights the significant role of soil in determining the seasonal variation of soil rhizospheric fungal diversity under *Musa* cultivars.

8 PSF were screened from the rhizosphere of *Musa* cultivars during the present study. Maximum PSF was reported under longer a fallow period in the order JL<AJL3<AJLB<AJL12 (**Table 13**). The decreased PSF at JL is due to the regular anthropogenic disturbances and the increased cropping cycle. Whereas, the introduction of fallow and vegetation positively affects the PSF population leading to increased diversity. Such increased PSF significantly increases the phosphate-solubilizng activity in the rhizosphere region (Suyal *et al.,* 2021). The study also report on the maximum PSF belonging to genera *Aspergillus* and *Penicillium*. The increased solubilizing capacity of these genera as compared to the other genera may be due to the increased production of organic acids or by the formation of complexes with the cations of the P (Johnston, 1959;

Fox *et al*., 1990). This is also agreement with workers who similarly reports on maximum PSF belonging to these genera (Nahas, 1996; Suyal *et al*., 2021).

6.4 SUMMARY AND CONCLUSION

The present chapter highlights the fungal diversity of *Musa* cultivars under different fallow lands in Mokokchung, Nagaland. A total of 36 fungal species were isolated under rhizospheric soils of *Musa* cultivars during the present study with maximum genera belonging to *Penicillium* and *Aspergillus*. The lowest diversity was reported at site JL (19) with *Penicillium* sp. 1 and *Aspergillus* sp. 1 possessing the highest percentage contribution. At site AJL3, 25 fungal species were isolated, with the highest percentage contribution recorded belonging to *Penicillium citrinum*. At site AJLB, a total of 30 fungal species were isolated, with highest percentage contribution recorded belonging to *Penicillium* sp. 4. Lastly, at AJL12, a total of 32 fungal diversity was recorded with highest percentage contribution belonging to *Aspergillus flavus* (5.54) and *Aspergillus niger* (5.54) respectively. The result of the various diversity indices also displays the reduced diversity and evenness at JL as compared to AJL3, AJLB and AJL12. The highest number of taxa (S) was reported at AJL12 were in the order: AJL12>AJLB>AJL3>JL. Similarly, the Simpons index of diversity and evenness was highest at AJL12>AJLB>AJL3>JL. Lastly, the Berger-Parker index value was highest at JL<AJL3<AJLB<AJL12. The implementation of the CCA also explains the spatial and temporal variation of the fungal community. The present study depicts the seasonal variation of fungal communities showing a similar trend with higher diversity during the warmer seasons and lesser fungal diversity during the colder season. The CCA depicts the role of the various soil variables in determining the fungal population, highlighting the role of soil fertility in determining the season variation. The fallow period is also reported to affect the PSF population. The study observed the decreased rhizospheric PSF at Jhumming sites, in contrast to the diversity of PSF which increases with the implementation of fallow. Lastly, maximum SI is reported belonging to genera *Aspergillus* and *Penicillium*, respectively. This highlights their potential utilizations as bio-fertilizers.

The study reports on the role of soil management in influencing the fungal diversity. The increased cropping cycle and fallow period reduction severely affect the fungal population on soils of JL. Anthropogenic disturbances such as firing and monocropping enable specific fungal communities to dominate, making the fungal

population disproportionate. The variation in soil fertility as the season changes also determines the fungal population. The maintenance of fallow leads to increased diversity leading to a balanced ecosystem. The study also reports on the beneficial aspect of bamboo introduction in fallow for the increased fungal diversity. The chapter highlights the importance of identifying fungal communities along the temporal and spatial scale to determine its quantitative and qualitative traits. The present study also highlights diverse fungal population in the rhizosphere region of the *Musa* cultivars in the region. Such information may also be utilized by researchers in in-vitro management of these cultivars for breeding purposes and conservation. There also is a need for good-quality inoculants to decrease the dependence on chemical fertilizers. The PSF screened in the present study may be therefore be subjected to future extensive field experiments to determine their viability. Considering the findings of the present chapter, our fourth hypothesis, "Shifting cultivation and fallow length affect the rhizospheric fungal diversity and population of *Musa* cultivars" is therefore accepted.

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ABBREVIATIONS

Short Form	Expanded Form
1-D	Simpson’s index of diversity
AJL12	An Abandoned Jhum land 12
AJL3	An abandoned Jhum fallow 3
AJLB	An Abandoned Jhum land with bamboo
BD	Bulk Density
BW	bunch weight
CCA	Canonical Correspondence Analysis
CEC	Cation Exchange Capacity
CFU	Colony forming unit
D	Berger–Parker index
DMRT	Duncan's Multiple Range Test
EC	Electrical conductivity
J	Pielou’s evenness
JL	A Jhum land 3
K_{AV}	Available potassium
MDS	Minimum data set
N_{AV}	Available Nitrogen
PCA	Principal Component Analysis
PDA	Potato Dextrose Agar
PVK	Pikovskaya
RBA	Rose Bengal Agar
Rip	Ripe peel
Ripu	Ripe pulp
S	Taxa

SI	**S**olubilization index
SOC	Soil organic carbon
SQI_a	Additive index
SQI_w	Weighted Index
TN	Total Nitrogen
Unp	Unripe peel
Unpu	Unripe pulp

UNITS

%	Percentage
cm	Centimeter
dS m^{-1}	deciSiemens per meter
g cm^{-3}	gram per cubic centimeter
Kg ha-^{1}	Kilograms per hectare
meq100g^{-1}	milliequivalents per 100 grams of soil
t ha−1 year−1	tonnes matter per hectare per year

Appendix I

Seasonal variation of soil physico-chemical properties under JL

Site	Season	Soil depth (cm)	pH	EC ($dS\ m^{-1}$)	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	Total Nitrogen (%)	Sand (%)	Silt (%)
JL	Spring	0-10	5.5±0.02	0.091±0.001	2.11±0.01	314.00±8.2	118.40±1.69	23.00±0.89	29.0±0.8	1.66±0.03	22.3±1.24	13.35±1.3	0.83±0.0.1	52.66±0.577	22.66±0.57
		10-20	5.8±0.08	0.088±0.002	1.37±0.02	223.00±5.0	94.33±3.39	21.53±0.41	32.6±2.8	2.30±0.08	20.1±1.54	14.30±2.09	0.81±0.01	53.03±0.05	23.03±0.057
		20-30	5.4±0.13	0.096±0.001	1.10±0.16	211.00±9.0	114.16±8.98	25.08±1.14	33.0±3.2	2.71±0.01	19.3±2.05	12.03±0.8	0.78±0.07	53.33±0.57	23.133±0.23
	Summer	0-10	5.6±0.03	0.161±0.014	1.74±0.21	320.88±5.2	132.53±13.48	27.7±1.35	37.7±1.4	1.33±0.24	22.6±2.05	15.75±2.1	0.966±0.04	50.46±0.45	21.46±0.50
		10-20	5.5±0.24	0.142±0.001	1.33±0.07	319.66±14.1	95.95±16.97	21.75±1.25	34.9±2.1	2.19±0.09	20.2±2.40	14.71±1.6	0.92±0.04	50.60±0.52	21.66±0.57
		20-30	5.8±0.09	0.135±0.005	1.19±0.14	305.33±9.6	109.78±6.13	19.95±2.53	30.7±1.7	1.48±0.11	18.9±3.02	13.38±2.8	0.91±0.100	50.66±0.577	21.63±0.55
	Autumn	0-10	5.9±0.10	0.120±0.008	2.16±0.39	391.33±10.1	133.72±5.56	21.06±1.63	43.8±0.9	1.70±0.30	28.3±0.47	19.28±0.3	1.03±0.05	48.66±0.577	22.033±0.57
		10-20	5.7±0.16	0.120±0.007	1.46±0.18	337.00±2.9	117.75±6.46	22.02±0.78	41.1±1.2	1.72±0.04	26.0±2.44	18.35±0.8	1.00±0.10	49.10±0.17	21.833±0.76
		20-30	5.6±0.13	0.116±0.004	1.37±0.26	278.33±47.4	126.42±2.04	19.58±1.05	42.1±0.3	2.72±0.05	24.7±3.63	18.38±0.6	0.933±0.05	47.63±3.19	22.23±0.11
	Winter	0-10	5.4±0.04	0.087±0.000	1.44±0.03	252.66±2.6	85.93±1.71	10.00±0.88	24.2±1.1	1.79±0.01	22.1±0.26	9.70±1.2	0.850±0.05	51.330.63	23.966±0.057
		10-20	5.4±0.16	0.091±0.002	1.19±0.07	192.33±10.9	77.23±1.32	9.46±0.12	27.3±0.7	2.88±0.05	20.5±0.63	9.72±0.1	0.82±0.100	51.66±0.577	24.66±0.57
		20-30	5.5±0.03	0.085±0.002	1.08±0.01	146.00±9.8	65.93±3.81	8.16±0.24	27.0±0.7	2.28±0.02	18.1±1.02	9.66±0.04	0.75±0.41	52.91±.057	25.3±0.60

Seasonal variation of soil physico-chemical properties under AJL3

Site	Season	Soil depth (cm)	pH	EC ($dS\ m^{-1}$)	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	Total Nitrogen (%)	Sand (%)	Silt (%)
AJL3	Spring	0-10	5.0±0.16	0.417±0.003	2.02±0.12	341.66±6.7	112.18±7.33	30.50±1.22	32.2±0.9	1.42±0.02	24.1±0.62	18.34±2.05	1.2±0.15	50.33±0.577	25.30±0.20
		10-20	5.1±0.12	0.411±0.001	1.93±0.22	377.66±13.1	91.65±8.60	27.03±0.91	34.0±0.8	1.45±0.01	24.4±1.74	17.46±1.1	1.13±0.57	51.00±1.00	25.20±0.34
		20-30	5.1±0.07	0.403±0.009	1.40±0.28	299.73±17.2	102.32±0.57	22.23±2.98	33.2±2.6	1.86±0.05	22.7±2.33	17.44±0.1	1.01±0.05	51.33±1.52	25.33±0.57
	Summer	0-10	5.1±0.09	0.543±0.004	2.81±0.24	324.00±10.0	145.46±5.76	28.90±0.28	39.5±0.4	1.43±0.01	27.1±0.82	23.18±1.1	1.30±0.005	47.00±1.10	24.96±0.05
		10-20	5.7±0.06	0.552±0.019	2.78±0.23	371.66±23.6	131.83±2.99	28.30±1.41	35.7±2.8	1.22±0.18	26.4±1.22	21.96±2.1	1.26±0.03	47.10±0.10	25.00±0.100
		20-30	5.1±0.14	0.530±0.007	2.31±0.18	356.67±20.5	117.56±12.65	27.43±1.08	31.8±2.0	1.73±0.03	26.7±0.88	20.87±1.1	1.2±0.01	47.40±0.458	25.36±0.55
	Autumn	0-10	5.7±0.59	0.372±0.013	2.13±0.18	451.33±5.2	171.36±15.39	30.72±1.90	48.8±0.8	1.30±0.15	29.3±0.47	22.12±2.57	1.31±0.15	46.30±1.05	25.300±0.51
		10-20	5.0±0.24	0.355±0.004	2.30±0.27	379.00±13.7	135.26±11.96	28.68±0.53	47.1±0.8	1.48±0.01	27.3±1.24	19.77±0.3	1.27±0.05	47.2±0.34	25.66±0.577
		20-30	5.7±0.36	0.342±0.010	1.93±0.22	236.00±38.1	148.36±3.18	26.22±2.40	45.5±1.5	1.65±0.01	26.0±2.44	19.72±0.4	1.20±0.005	47.30±0.43	26.00±1.00
	Winter	0-10	5.1±0.16	0.285±0.002	1.76±0.04	295.33±5.2	91.26±1.10	17.56±0.33	28.6±0.4	1.67±0.01	26.0±0.16	15.76±1.2	1.10±0.005	48.033±0.057	27.90±0.17
		10-20	5.1±0.20	0.240±0.016	1.70±0.01	283.00±12.2	89.76±6.99	17.17±0.22	29.1±3.6	1.76±0.02	25.1±2.24	16.00±0.08	1.07±0.05	48.00±1.10	27.86±0.23
		20-30	5.0±0.32	0.228±0.005	1.40±0.05	202.00±7.3	83.10±3.14	16.58±0.40	26.0±3.6	1.93±0.03	24.6±0.49	14.86±0.1	0.99±0.11	48.36±0.63	28.2±0.34

Seasonal variation of soil physico-chemical properties under AJLB

Site	Season	Soil depth (cm)	pH	EC (dSm^{-1})	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	Total Nitrogen (%)	Sand (%)	Silt (%)
AJLB	Spring	0-10	5.2±0.15	0.512±0.007	3.06±0.22	540.00±39.0	211.22±19.89	33.70±6.98	42.36±4.9	1.21±0.01	29.3±1.44	26.77±2.2	1.64±0.015	42.50±0.50	25.83±0.76
		10-20	5.1±0.04	0.500±0.006	3.00±0.21	500.11±22.8	200.11±14.77	29.17±3.69	39.33±5.9	1.21±0.02	28.1±2.99	26.03±3.4	1.56±0.055	42.33±0.577	26.033±0.057
		20-30	5.2±0.09	0.501±0.014	2.78±0.33	501.12±11.7	187.59±21.10	29.32±8.88	39.36±3.1	1.23±0.06	27.7±8.26	25.21±7.3	1.54±0.069	43.33±0.57	26.033±0.057
	Summer	0-10	5.29±0.11	0.649±0.013	3.26±0.16	560.00±12.8	222.22±19.88	35.22±9.11	53.66±3.9	1.16±0.07	33.2±5.17	28.11±4.3	1.66±0.43	37.33±0.577	29.76±0.40
		10-20	5.28±0.07	0.614±0.027	3.17±0.10	530.11±15.2	236.99±15.09	34.66±3.57	53.26±1.5	1.17±0.04	30.2±3.88	25.01±4.4	1.58±0.26	37.66±0.577	30.33±1.52
		20-30	5.01±0.02	0.608±0.002	3.04±0.36	468.10±18.9	198.44±33.47	32.33±3.88	49.33±9.7	1.13±0.05	30.2±6.57	26.10±2.3	1.52±0.26	37.77±1.27	30.30±0.60
	Autumn	0-10	5.39±0.05	0.633±0.013	3.19±0.12	566.13±19.9	277.88±22.27	39.44±7.88	56.87±2.6	1.09±0.01	33.1±3.55	29.28±3.6	1.70±0.11	33.03±0.57	31.96±0.05
		10-20	5.3±0.06	0.629±0.007	3.00±0.22	528.10±22.6	255.44±39.22	36.91±4.05	55.41±2.7	1.08±0.01	31.8±1.42	28.77±2.4	1.70±0.05	33.10±0.17	33.36±1.58
		20-30	5.28±0.26	0.611±0.012	2.99±0.35	500.13±24.1	256.55±32.16	35.77±1.05	53.12±2.5	1.09±0.01	30.3±4.98	29.72±1.3	1.69±0.05	33.33±0.577	32.300±0.51
	Winter	0-10	4.5±0.08	0.519±0.009	2.87±0.07	450.00±6.4	119.36±11.73	28.43±6.52	36.46±7.5	1.42±0.02	28.1±2.16	24.14±4.6	1.60±0.05	40.33±0.577	27.83±0.28
		10-20	4.5±0.02	0.512±0.002	2.33±0.08	422.33±22.1	109.88±21.28	26.13±3.21	35.30±5.2	1.55±0.03	27.7±7.57	23.56±8.7	1.59±.005	40.63±0.55	28.00±0.100
		20-30	4.9±0.19	0.508±0.003	2.08±0.91	388.10±14.6	101.66±19.88	26.02±5.6	32.90±2.5	1.55±0.06	26.8±3.58	23.44±2.7	1.58±0.02	40.00±2.64	27.66±0577

Seasonal variation of soil physico-chemical properties under AJL12

Site	Season	Soil depth (cm)	pH	EC ($dS\ m^{-1}$)	SOC (%)	N_{av} ($Kg\ ha^{-1}$)	K_{ex} ($Kg\ ha^{-1}$)	P_{av} ($Kg\ ha^{-1}$)	Moisture (%)	BD ($g\ cm^{-3}$)	Clay (%)	CEC ($meq100g^{-1}$)	Total Nitrogen (%)	Sand (%)	Silt (%)
AJL12	Spring	0-10	**4.5±0.21**	0.684±0.007	4.08±0.25	545.66±10.6	206.43±18.92	38.61±0.62	52.15±0.8	1.01±0.01	33.9±3.77	29.79±5.4	1.72±0.05	40.00±0.57	22.96±0.05
		10-20	**4.8±0.11**	0.670±0.001	3.75±0.10	554.66±30.4	184.10±13.23	37.07±1.58	52.66±3.4	1.04±0.03	32.0±2.16	26.07±4.1	1.72±0.023	39.96±0.55	24.00±1.73
		20-30	**5.1±0.23**	0.664±0.006	2.72±0.22	388.00±13.4	188.52±6.50	34.91±2.57	49.06±0.6	1.03±0.01	31.2±1.11	25.68±0.4	1.68±0.17	39.68±1.62	24.33±1.52
	Summer	0-10	5.0±0.17	0.836±0.020	3.85±0.04	563.00±25.8	233.24±8.279	40.66±1.21	55.06±1.0	1.00±0.01	36.0±2.02	33.51±1.56	1.73±0.03	36.733±0.90	27.33±0.577
		10-20	5.1±0.08	0.761±0.009	3.43±0.14	459.44±14.7	247.63±17.10	38.13±1.80	56.20±0.9	1.00±0.01	34.9±1.30	31.25±1.4	1.69±0.005	37.36±0.63	27.63±1.09
		20-30	5.1±0.02	0.747±0.018	3.11±0.20	427.33±21.8	213.67±7.96	37.63±1.721	52.28±3.6	1.10±0.01	33.6±2.25	30.56±3.3	1.63±0.11	36.400±0.52	27.93±0.115
	Autumn	0-10	5.0±0.04	0.743±0.022	4.12±0.18	573.00±13.1	294.46±3.41	36.93±3.00	59.47±0.8	0.96±0.04	37.2±0.71	37.27±1.34	1.80±0.005	30.10±0.17	31.66±0.577
		10-20	5.2±0.07	0.735±0.018	3.3±0.13	512.11±10.5	252.13±25.38	34.21±0.89	58.07±0.7	1.00±0.01	35.8±0.18	35.99±0.07	1.79±0.005	30.33±0.57	32.20±0.43
		20-30	5.0±0.04	0.653±0.016	3.13±0.08	497.76±2.1	279.83±14.09	33.61±1.09	56.51±1.2	0.99±0.01	33.3±3.68	33.78±1.6	1.66±0.01	30.33±0.57	32.00±1.00
	winter	0-10	4.8±0.13	0.683±0.009	3.72±0.11	490.33±10.2	124.90±2.84	29.10±0.16	49.39±1.4	1.07±0.01	31.7±1.28	29.36±1.6	1.65±0.08	32.86±0.23	35.900±0.173
		10-20	4.9±0.08	0.653±0.016	3.04±0.02	405.33±4.9	120.12±6.33	25.63±3.81	49.66±3.7	1.14±0.01	32.3±0.49	28.90±0.1	1.69±0.05	33.36±0.63	35.70±0.60
		20-30	4.3±0.30	0.667±0.005	2.56±0.18	402.00±32.6	115.21±1.78	24.46±1.22	46.30±1.4	1.16±0.02	30.8±1.22	29.26±0.2	1.65±0.14	33.06±0.05	36.30±0.26

Appendix II

Critical limits of soil quality indicators of Aot Mungo

Soil properties	Critical limits (%)		
pH	40	5.909806	$r^2 = 0.8609$
	80	5.261215	
EC (dS m^{-1})	40	0.1752171	$r^2 = 0.895$
	80	0.4256045	
SOC (%)	40	0.420874	$r^2 = 0.9192$
	80	2.436485	
N_{av}(Kg ha^{-1})	40	137.3095	$r^2 = 0.9465$
	80	385.3667	
K_{av} (Kg ha^{-1})	40	34.84195	$r^2 = 0.9871$
	80	151.4346	
P_{av} (Kg ha^{-1})	40	11.15394	$r^2 = 0.9453$
	80	27.35254	
Moisture (%)	40	16.80322	$r^2 = 0.9868$
	80	41.13362	
BD (g cm^{-3})	40	2.547741	$r^2 = 0.884$
	80	1.472506	
Clay (%)	40	14.76626	$r^2 = 0.9335$
	80	28.22906	
CEC (meq100g^{-1})	40	3.771227	$r^2 = 0.9563$
	80	22.97064	
TN (%)	40	0.4220833	$r^2 = 0.9569$
	80	1.3220833	
Sand (%)	40	61.006521	$r^2 = 0.9874$
	80	43.86398	
Silt (%)	40	19.406351	$r^2 = 0.9124$
	80	26.773461	

Critical limits of soil quality indicators of Atsu Mungo

Soil properties	Critical limits %		
pH	40	5.78922	$r^2 = 0.928$
	80	5.20173	
EC (dS m^{-1})	40	0.05703	$r^2 = 0.9406$
	80	0.4802	
SOC (%)	40	0.80866	$r^2 = 0.976$
	80	2.62031	
N_{av} (Kg ha^{-1})	40	196.099	$r^2 = 0.9002$
	80	407.11	
K_{av} (Kg ha^{-1})	40	62.4341	$r^2 = 0.9398$
	80	161.658	
P_{av} (Kg ha^{-1})	40	14.6249	$r^2 = 0.9518$
	80	28.8017	
Moisture (%)	40	21.996	$r^2 = 0.9956$
	80	43.3119	
BD (g cm^{-3})	40	2.317	$r^2 = 0.89$
	80	1.376	
Clay (%)	40	17.4631	$r^2 = 0.9725$
	80	29.4484	
CEC (meq100g^{-1})	40	8.18764	$r^2 = 0.9258$
	80	24.6642	
TN (%)	40	0.621719	$r^2 = 0.946$
	80	1.402139	
Sand (%)	40	57.01306	$r^2 = 0.9493$
	80	42.35434	
Silt (%)	40	20.9588	$r^2 = 0.9271$
	80	27.43528	

Appendix III

One way ANOVA with post hoc test DMRT between the proximate compositions of Aot Mungo

Plant part	Protein		Moisture		Ash		Crude fibre		Crude Fat		Total Carbohydrate	
	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value
Unp	234.49	<0.001	1.03	0.428	2.599	0.125	2.59	0.125	2.874	0.103	464.636	<0.001
Rip	105.15	<0.001	1.224	0.362	5.427	0.025	5.42	0.025	2.021	0.190	516.58	<0.001
Unpu	9.18	0.006	133.28	<0.001	6.617	0.015	6.617	0.015	3.645	0.064	46.29	<0.001
Ripu	7.60	0.010	11.60	0.003	6.217	0.017	6.217	0.017	5.554	0.023	0.433	0.735

Variation is significant at 5% level by Duncan's multiple range test (p=<0.05).

One way ANOVA with post hoc test DMRT between the proximate compositions of Atsu Mungo

Plant part	Protein		Moisture		Ash		Crude fibre		Crude Fat		Total Carbohydrate	
	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value	F-value	*p*-value
Unp	0.459	0.718	0.459	0.718	7.141	0.012	71.64	<0.001	71.64	<0.001	4.072	0.50
Rip	2.756	0.111	2.767	0.111	113.38	<0.001	14.79	0.001	14.79	0.001	3.12	0.088
Unpu	8.090	0.008	8.090	0.008	4.237	0.001	251.51	<0.001	251.510	<0.001	71.26	<0.001
Ripu	5.930	0.020	5.930	0.020	14.75	0.001	37.22	<0.001	37.22	<0.001	71.26	<0.001

Variation is significant at 5% level by Duncan's multiple range test (p=<0.05).

Appendix IV

Morphological descriptors of fungal colonies

fungal species	Identification keys
Absidia sp. Tiegh. (1878)	Colonies reached 1-2.1 cm in 5-6 days. Colonies grey in color, reverse white. Sporangiospores 2-3.2 µm long, zygospores covered with stellate projections to 4.1 µm long, finger-like appendages arising from suspensors
Acremonium murorum Gams (1971)	Colonies reached 1.5-3 cm 6-7 days. Colonies white in color, reverse colourless. Distinct septate, hyaline and branched hyphae with phialides. Phialides septate, hyaline, 15-38 µm long and 1.2-3.1 µm wide with basal septum tapered towards the apex with conidial masses. Conidia solitary, 1-celled, elongate ellipsoidal, cylindrical to oval, 2.9-3.4 x 1.5-2.4 µm.
Acremonium strictum Gams (1971)	Colony reaches 1.6-2.5 cm in 10 days. Colonies pinkish white in color with characteristic pungent odor, reverse colorless. Sporogenous cells phialidic, simple, arising from submerged or slightly fasciculated aerial hyphae. Conidia 1cylindrical 3.3-5.5 x 0.9-1.8 µm.
Aspergillus candidus Link ex Link (1824)	Colonies relatively slow growing, 1-3.0 cm diameter in 13-15 days. Cottony white in PDA, reverse white. Conidiophores large globose, vesicles bearing club shaped metulae. Narrow philaides. Globos conidia, smoth walled. 2.5-3.5 µm meter, uninucleate
Aspergillus flavus Link (1809)	Colonies 3.5-4 cm in 5 days. Colony initially yellow-green which then becomes dark green, reverse light brown,. Conidiophores hyaline, rough walled bearing vesicle. Vesicles globose to subglobose. Conidial heads radiating, biseriate and uniseriate. Phialides bearing conidia measuring 3-4.4 µm in diameter, smooth and aseptate.
Aspergillus fumigatus Fresenius (1863)	Colony reaching 0.7-1.9 cm in 5-6 days days. Colony greenish-brown with exudate and white margins, velvety, reverse brown in color. Conoidiophores sub-hyaline, straight to flexuous, smooth and aseptate, 2.4-3µm wide. Vesicles globose to sub-globose, conidial heads sub-spherical, phialides borne directly on the vesicle and uniseriate. Conidial head erect, compact and columnar. Conidia globose, echinulate and 1.5-2µm in diameter
Aspergillus niger van Tieghem (1867)	Colony reaching 1.8- 2.4 cm in 5 days. Colonies black with white margin, reverse colorless to brown. Conidiophores sub-hyaline and pale brown, erect, smooth, unbranched, aseptate and 7.6-9 µm wide and 300-500 µm long. Phialides 7-8 µm long and 3-4 µm wide. Conidial heads biseriate, brown black to black with globular, aseptate unbranched chain of conidia. Conidia mostly measured 3-3.4 µm in diameter and appeared brownish, globose and rough.
Aspergillus sp.1 Micheli (1729)	Colony 2.9- 3.7 cm in 7 days. Colony greenish-green, velvety, reverse light to dark. Conidiophores long, aseptate, hyaline, smooth-walled, 3-5 µm wide, 300- 800 µm long. Phialides 5-6 µm long, conidia smooth and globose, 2-3 µm diameter
Aspergillus sp. 2.	Colony 2.5- 3.4 cm in 7 days. Colony top yellowish green, velvety, revserse colorless to light brown. Conidiophores hyaline, erect, aseptate, smooth-walled, 120-240 µm long, 3-5 µm wide. Phialides 2.2-3 µm wide and 3-4 µm long. Vesicles 10-30 µm diameter, globose. Conidia 2-3 µm in diameter and globose.
Aspergillus versicolor Tiraboschi (1908)	Colonies raaches 1.7-1.9 cm, brownish green with dark brown coloured exudates, revsere colourless. Conidiophores hyaline, smooth-walled, closely interwoven mycelium and 210-700µm long, sub-globose, biseriate. Phialides 5-8µm long and 2-

	2.5 µm wide. Vesicles 9-15 µm diameter and pyriform. Conidia ellipsoidal, rough, hyaline and 2- 3.6 µm diameter.
Chaetomium globosum Kunze (1817)	Colony 3- 4 cm, in 7 days. Colony colour white to grey, revsere yellow to dark colour. Ascomata dark brown, globose to subglobose, 170-250µm wide and 200-350µm long, lateral hair dark brown radiating in all directions. Terminal hairs dark olive-brown, 3.3-4.5 µm wide. Asci hyaline and clavate. Ascospores ellipsoidal, apiculate ends and 6-8 µm wide
Cladosporium cladosporiodes (Frescen.) de Vries (1952)	Colonies in 5 days were 1.6-3.3 cm. Colony colours first whitish-grey becoming olivaceous brown, velvety, reverse black. Hyphae septate and branched. Condiophore straight, short, branched, solitary with 3 to 4 cylindrical ramoconidia, 300-350 µm long and 3.5-6.5 µm wide. Conidia numerous, branched, one-celled, ellipsoidal to lemon shaped, smooth walled, 3-5 µm long and 2-2.5 µm wide.
Cladosporium oxysporum Berk and Curtis (1868)	Colonies reaching 1.5- 3 cm in 5 days. Colonies color grey, floccose, slightly raised, irreugular, reverse colourless. Hyphae septate and branched, 2.2-5.8 µm wide. Conidiophore long, cylindrical to filiform, unbranched with intercalary swelling, 2-4 x 230-250 µm. Conidia ovoid to cylindrical, greyish brown, 1-celled.
Eupenicillium javanicum Stolk and Scott 1967	Colonies growing rapidy, reaches 3-4cm in 12-14 days. Colonies were cottony white and green, reverse colourless. Ascomyta about 100-150 micro metre, Penicilli sancty usually monoverticiliate with lateral branch, smooth walled, 2-6 philidases, conidia pear shaped, 2.3-3.0x1-2 M m, uninucleate.
Fusarium sp.1 Link (1809)	Colonies reaching 3.1-4 cm in 5 days respectively. Colony color creamy white to purple, reverse colorless. Conidiophore septate, hyaline and branched. Macroconidia hyaline, curved apical cell, to slightly curved, straight poorly developed basal cells, 3.2-4.4 x 25.1-45.4 µm. Microconidia oval to bean-shaped, 0 septa, produced on monophialides and polyphialides, 2-3 x 25-45 µm. Chlamydospore absent.
Fusarium sp. 2.	Colonies reaching 3.1-3.8 cm in 5 days. Colony colours pinkish-white reverse colourless. Colonies cottony, floccose, little aerial mycelium, irregular to regular and entire. Hyphae hyaline, septate and branched. Macroconidia hyaline, curved, smooth, apical cell short and blunt, tapering ends, 3-5 septa, 4.5-7.1 x 45-73.4µm.
Geotrichum candidum Link. (1809)	Colonies reaching 2.5-3.5 cm in 5 days. Colony color creamy white, reverse. Colonies yeast-like, spreading, soft, raised in the center, irregular with a fruity odour. Mycelium hyaline, septate and sporulating. Hyphae septate, hyaline and branched, 3.2-5 µm wide. Anthroconidia rectangular, thick wall, 1-celled, 3-10 x 2-5 µm. Chalamydospores subglobose, solitary and 4-6 µm in diameter. Conidia in chains, 1-celled and cylindrical, arthosporous, smooth, 5-15 x 3-6 µm.
Humicola sp. Traaen 1914	Colonies 2-3 cm in 10-12 days. Colony colour greyish, revere lighter later beomcing greyish black. Alericonidia 10-12 micron meter. Phialaconidida present in isolates, obovoid, 3-5x1.5-2.5 micro meters. Hyphal cells and aleuroconidia plurinucleate, uninucleates.
Mortierella sp. Coem. (1863)	Colonies reaching 3.3-3.6 cm in 5 days. Colony color milky white, cottony, reverse cream. Conidiophores unbranched, less than 100 µm in length, aseptate, slightly widened below sporangium. Sporangia globose, smooth, 9-11µm in diameter, small chlamydospores abundantly present, thick walled, irregular in shape, 9-10 µm in diameter. Conidia globose, 9-11 cm in diameter.
Mucor circinelloides Tiegh (1875)	Colonies reaching 2.3-3.2 cm in 5 days. Colony color white turning whitish-grey reverse colorless. Colony fast growing, cottony, floccose, turf thick, raised and irregular. Sporangiophores were branched sympodially, hyaline terminated by

	sporangium, erect, slightly curved, 2.5-5 x 20-24 µm. Columellae present. Sporangiospores were globose, echinulate, columellate on dehiscence and 20-23.5 µm in diameter. Columellae hyaline, ellipsoidal, with a collar. Chlamydospores subglobose, 12-22 µm wide. Spores subglobose, 1-celled and 3.3-4.4 x 2.4-3.5 µm.
Mucor heimalis Wehmer (1903)	Colony reaching 2.4-3.1 cm 5 days. Colony color grey, reverse colorless to pale yellow. Colonies cottony, floccose, aerial mycelium and smooth. Sporangiophores 10-13 µm wide, erect, branched sympodially. Sporangia globose, columellate on dehiscence, 52-68.7 x 61.3-80 µm. Columellae globose to subglobose, truncate base, with a collar, 15-30 µm wide. Chlamydospores globose, 9-16 µm wide. Spores subglobose to ellipsoidal, 1-celled and 2.4-4 µm.
Mucor plumbeus Bonord (1864)	Colony reaching 1.3-3 cm, in 5-7 days. Colony color dark grey, reverse colorless. Colonies thick tufts, cottony, aerial mycelium, raised, soft, entire, smooth and round. Sporangiophores branched both sympodially and monopodially, constricted towards sporangium, 16-20.5 µm wide. Sporangia hyaline, columellae pyriform, obovoid, ellipsoidal to cylindrical, brown and 62-70 x 28-43 µm. Sporangiospores globose to ellipsoidal or irregularly shaped, 5.6-8.2 µm in diameter, yellowish brown. Chlamydospores absent.
Paecilomyces carneus Brown and Smith (1957)	Colony reaches diameter 1.5-2.5 cm in 14-15 days. Slow growth, pink colonies, reverse dark green. Slender philades, narrow neck, rough walled conidia 3-4x2-3 µm
Paecilomyces farinosus Brown and Smith (1957)	Colonies reaching 4-6 cm diameter in 14-15 days. Powdery white turning bright green or yellow, reverse colourless. Conidiophores usually erect, 100-300 micron meter tall, bearing whorls of flash shaped philiades. Conidia ellipsoidal to fusiform 2.0-3.0x 1-1.8 mcion meter. Synnemata upto 1-3 cm long
Penicillium brevicompactum Dierckx (1901)	Colony reaches 1.5-2.5 cm in 14 days. Greysinsh green colonies, reverse brown. long conidophores. Slow growing. Conidia globose to subglobose, rough, mostly 3.5-4.0 Micro meters
Penicillium citrinum Thom (1910)	Colony diameters reaches 2.1 - 2.6 cm in 5 days. Colony color dark green, powdery, reverse colorless to light orange. Conidiophores long, raised from subsurface hyphae, 100–300 µm long. Hyphae monoverticilate to terverticilate, smooth-walled stipes, metulae cylindrical. Phialides ampulliform and 7–9.5 x 2-2.5µm. Conidia globose to sub- globose and 2.2-3.5 µm.
Penicillium digitatum Sacc (1882)	Colony reaching 1 cm in 10-14 days. Mostly greenish brown reverser uncoloured or dull tan. Conidia cylindrical and rounded tip, 4-5.0 mciron metere. Odour of decaying fruits.
Penicillium sp.1 Link (1809)	Colony reachese 2.3-3 cm in 5 days. Colony colour creamish-yellow, reverse colourless. Colonies were slightly velvety, granular, round to undulate and wrinkled. Hyphae septate and hyaline. Conidiophore hyaline, erect, unbranched, septate, monoverticillate. Metulae absent. Phialides ampulliform, hyaline, 2.8-4.1 x 9-11.7 3.2-4.5 µm. Conidia 1-ceeled, hyaline, globose, 3.1-3.8 µm.
Penicillium sp.2 Link (1809)	Colony reaches 2- 3.7 cm in 7 days. Colony white at first and turned bluish-green, reverse bottom colourless cream. Colonies were velvety with brown exudates on MEA and CDA plates, entire, round and raised, wrinkled, undulate. Hyphae septate, hyaline, smooth-walled. Conidiophores hyaline, erect, raised from the surface, stipes smooth, simple, terverticilate. Metulae cylindrical and phialides ampulliform. Conidia 1-celled in short chains, globose, 3-3.5 µm wide
Penicillium sp.3 Link (1809)	Colony diameters reaches 2.5-3.2 cm in7 days. Colony colors blue-green to grayish, reverse colorless. Colonies velvety to powdery, flat on margins and raised in the

	center of the colony, wrinkled and irregular. Hyphae hayaline and septate. Conidiophores arises from the hyphae, 150-700 µm, stipes smooth –walled, terverticilate. Metulae 3-4, cylindrical, 7.3-13 µm x 3-4 µm. Philiades ampulliform. Conidia globose , 2.5-3 µm wide.
Penicillium sp. 4 Link (1809)	Colony reaches 2-2.5 cm in 5 days. Colony colour green, revserse. Colonies with exudates, velvety, pale yellow margin around the colonies. Conidiophore biverticillate borne on the hyphae, smooth-walled, 210-440 µm long stipes. Metulae cylindrical, 4.4-5.8 µm long, ampuliform. Phialids 6.1-8.4 µm long. Conidia globose and 2.2-3 µm diameter.
Rhizopus sp. Tiegh (1875)	Colonies reaches 1.8-2.5 cm in 5 days. Colony color brown, reverse colorless. Colonies were floccose, cottony, aerial mycelium, and entire. Hyphae hyaline and branched. Sporangia globose to sub-globose, columellate on dehiscence, 80.5-100 µm in diameter. Sporangiophores solitary to groups, unbranched, erect, connected by stolons, 7.6- 15.7 µm wide. Apophyses noticeable. Stolons hyaline, 3.5-7 µm wide. Rhizoids subhyaline. Conidia cylindrical, striated and 3.4-4.3 x 5.2-6.5 µm.
Scopulariopsis sp. Bainier (1907)	Colonies reaches in diameter 0.8-1.4 cm in 5 days. Colonies initially white becoming grey, reverse smoke grey to black. Mycelial hyphae hyaline, annellophores solitary, conidiogenous cells ampulliform, 4-9.5 x 2.2-3.5 µm. Conidia ovoid, truncate at base, dark brown, smooth-walled, in chains, 4.2-5 x 3.1-4.3 µm.
Trichoderma harzianum Rifai (1969)	Colonies reaching a diameter of 4.1-5 cm in 5 days. Colonies whitish green to yellowish reverse colorless to pale yellow. Colonies appeared as powdery, floccose, with concentric rings, raised and entire. Hyphae septate and hyaline. Conidiophores hyaline, bearing right angled branches to the tip, erect, 60.5-103 µm long. Phialides 2-3 in each branch, flask shaped and appeared in pairs, 3-6.5 µm long. Conidia short, 2.6µm in diameter, globose, smooth and 1-celled. Conidia short, globose, smooth and 1-celled, 2.6 µm in diameter. Chlamydospore sub-globose, 6.6-8.1 µm in diameter.
Tricoderma viride Pers (1974)	Colonies reaching 3.1-4.3 cm within 5 days. Colony appeared as white becoming yellowish- white and light-green, revserse colourless. Colonies slightly raised to flat, floccose, undulate, powdery with a yellowish ring, white pustules and green conidia appered on the surface of the colonies. Hyphae branched, septate and hyaline. Conidiophore branched, right angled, erect, hyaline with 2-3 phialides in opposite pairs, solitary or in whorls, cylindrical to board in the middle, ampulliform, flask-shaped, 2-3.5 x 6.8-11 µm. Conidia globose to obovoid, 1-celled, hyaline, 2.8-4.3 x 3.2-4 µm. Chlamydospore globose to sub-globose, intercalary and 5.3-6.9 µm in diameter.
Trichophyton sp. Malmstem 1845	Colonies reacing 1.5-2 cm in 5 days.whitish with smooth walled conidia, reverse yellow-brown. Producing both macro and micro conidia, Macroconidia well differentiated, 2 µm, macro conidia 3.6 celled, 15-20x 4-6 µm.

Appendix V

Percentage contribution of the fungal population form the study sites

JL

	Fungal diversity	Percentage Contribution
1	*Absidia* sp.	0.724638
2	*Aspergillus candidus*	1.086957
3	*Aspergillus flavus*	5.797101
4	*Aspergillus fumigatus*	3.623188
5	*Aspergillus niger*	4.710145
6	*Aspergillus* sp. 1	10.50725
7	*Aspergillus* sp. 2	11.5942
8	*Chladosporium chaldosporiodes*	8.333333
9	*Eupenicillium javanicum*	3.985507
10	*Fusarium* sp. 1	0.362319
11	*Fusarium* sp. 2	1.086957
12	*Mortierella* sp.	9.057971
13	*Mucor circinelloides*	3.26087
14	*Paecilomyces carneus*	2.536232
15	*Penicillium* sp. 1	10.50725
16	*Penicillium* sp. 2	5.797101
17	*Penicillium* sp. 3	6.521739
18	*Rhizopus* sp.	3.985507
19	*Trichoderma harianum*	6.521739
	Total	100

AJL3

	Fungal diversity	Percentage Contribution
1	*Absidia* sp.	2.515723
2	*Acremonium murorum*	5.031447
3	*Acremonium strictum*	2.515723
4	*Aspergillus flavus*	6.603774
5	*Aspergillus fumigatus*	4.402516
6	*Aspergillus niger*	7.54717

7	*Aspergillus* sp. 1	6.918239
8	*Aspergillus* sp. 2	4.402516
9	*Chaetomium* sp.	2.830189
10	*Chladosporium chaldosporiodes*	5.974843
11	*Eupenicillium javanicum*	3.144654
12	*Fusarium* sp. 1	0.314465
13	*Geotrichum candidum*	5.660377
14	*Humicola* sp.	2.830189
15	*Mucor circinelloides*	1.886792
16	*Mucor hiemalis*	3.773585
17	*Paecilomyces carneus*	3.144654
18	*Paecilomyces farinosus*	3.773585
19	*Penicillium brevicompactum*	4.08805
20	*Penicillium citrinum*	11.63522
21	*Penicillium* sp. 1	0.943396
22	*Penicillium* sp. 2	3.144654
23	*Rhizopus* sp.	1.886792
24	*Trichoderma harianum*	1.886792
25	*Trichoderma viridie*	3.144654
	Total	100

	Fungal diversity	Percentage Contribution
1	*Absidia* sp.	1.587302
2	*Acremonium murorum*	4.126984
3	*Acremonium strictum*	2.539683
4	*Aspergillus candidus*	0.952381
5	*Aspergillus flavus*	4.444444
6	*Aspergillus fumigatus*	4.761905
7	*Aspergillus versicolor*	0.952381
8	*Aspergillus niger*	5.079365
9	*Aspergillus* sp. 2	4.761905
10	*Chaetomium* sp.	2.857143

11	*Eupenicillium javanicum*	3.492063
12	*Fusarium* sp. 1	0.952381
13	*Geotrichum candidum*	3.174603
14	*Humicola* sp.	3.174603
15	*Mortierella* sp.	2.539683
16	*Mucor circinelloides*	5.079365
17	*Mucor* sp.1	0.952381
18	*Paecilomyces carneus*	3.809524
19	*Paecilomyces farinosus*	2.539683
20	*Penicillium citrinum*	2.857143
21	*Penicillium digitatum*	5.396825
22	*Penicillium* sp. 1	2.222222
23	*Penicillium* sp. 2	2.222222
24	*Penicillium* sp. 3	3.809524
25	*Penicillium* sp. 4	8.888889
26	*Rhizopus* sp.	4.761905
27	*Scopulariopsis* sp.	3.174603
28	*Trichoderma harianum*	5.079365
29	*Trichoderma viridie*	1.904762
30	*Trichophyton* sp .	1.904762
	Total	100

AJL12

	Fungal diversity	Percentage Contribution
1	*Absidia* sp.	5.013193
2	*Acremonium murorum*	3.430079
3	*Acremonium strictum*	2.37467
4	*Aspergillus candidus*	1.583113
5	*Aspergillus flavus*	5.540897
6	*Aspergillus fumigatus*	4.485488
7	*Aspergillus versicolor*	3.693931
8	*Aspergillus niger*	5.540897

9	*Aspergillus* sp. 1	3.166227
10	*Chaetomium* sp.	2.902375
11	*Chladosporium chaldosporiodes*	3.957784
12	*Cladosporium oxysporum*	3.693931
13	*Eupenicillium javanicum*	4.74934
14	*Geotrichum candidum*	3.693931
15	*Humicola* sp.	0.527704
16	*Mortierella* sp.	2.638522
17	*Mucor circinelloides*	1.846966
18	*Mucor* sp. 1	0.791557
19	*Paecilomyces carneus*	2.638522
20	*Paecilomyces farinosus*	3.957784
21	*Penicillium brevicompactum*	1.583113
22	*Penicillium citrinum*	1.055409
23	*Penicillium digitatum*	4.221636
24	*Penicillium* sp. 1	4.74934
25	*Penicillium* sp. 2	2.638522
26	*Penicillium* sp. 3	3.693931
27	*Penicillium* sp. 4	3.693931
28	*Rhizopus* sp.	2.110818
29	*Scopulariopsis* sp.	1.319261
30	*Trichoderma harianum*	2.37467
31	*Trichoderma viridie*	3.693931
32	*Trichophyton* sp .	2.638522
	Total	100

Appendix VI

Diversity indices of the study sites

Indices	JL	AJL3	AJLB	AJL12
Taxa	19	25	30	32
Individuals	276	318	315	379
Simpson	0.923	0.9459	0.9579	0.9631
Pielou's evenness	0.7744	0.8471	0.8792	0.9052
Berger-Parker	0.1185	0.1164	0.08889	0.05541

Appendix VII

Eigenvalue and Percentage Variance obtained from the Canonical correspondence analysis

Site	Axis	Eigenvalue	Percentage Variance
JL	1	0.091179	53.34
	2	0.055958	32.74
	3	0.023805	13.93
	Axis	**Eigenvalue**	**Percentage Variance**
AJL3	1	0.12326	64.06
	2	0.042232	21.95
	3	0.026923	13.99
	Axis	**Eigenvalue**	**Percentage Variance**
AJLB	1	0.19414	52.32
	2	0.11669	31.45
	3	0.06024	16.23
	Axis	**Eigenvalue**	**Percentage Variance**
AJL12	1	0.16133	49.53
	2	0.10085	30.96
	3	0.063514	19.5

ABSTRACT

AGRO-ECOLOGICAL STUDIES ON TWO SELECTED *MUSA* CULTIVARS PLANTED IN CULTIVATED AND ABANDONED JHUM LAND OF MOKOKCHUNG DISTRICT, NAGALAND

THESIS SUBMITTED

TO

NAGALAND UNIVERSITY

IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD

OF

DOCTOR OF PHILOSOPHY IN BOTANY

By

Mr. WATITEMJEN

Registration No: Ph. D./BOT/00158

Date: 18/08/2018

DEPARTMENT OF BOTANY

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ABSTRACT

Agro-ecology includes the study of the ecology of the food system and the sustainable management of the food systems by applying adequate ecological concepts. This system of agricultural practice attempts to optimize the various ecological processes and minimize the dependency on external chemical input for creating sustainable and efficient biological interactions in nature. In fact, farming practices that employ agro-ecological principles significantly increase the sustainability of agriculture in regions of India, wherein the extreme depletion of natural resources as well as the socio-economic aspects may be regulated. Shifting cultivation, also called Jhum cultivation, slash and burn, Swidden, or rotational bush fallow agriculture dominates agriculture in North-East India. This system of agriculture forms the socio-cultural identity of the indigenous inhabitants. However, unsustainable means of soil practices such as reduction of fallow, increased cropping cycle, and monocropping may adversely affect the soil quality. This ultimately affects both the sustainability and livelihood security of the indigenous inhabitants.

Understanding agro-ecology at a regional level is essential to ensure optimum production and sustainable utilization of natural resources. Shifting cultivation has been attributed to large-scale deforestation, soil degradation and ultimately reduced productivity in the North East region of India. Therefore experimental sites were selected under Longsa village, Mokokchung district, Nagaland to understand the effects of fallow and Jhumming on soil quality and rhizospheric fungal diversity. The present investigation was carried out at 4 different sites, namely: Site JL: A Jhum land in its 3rd cycle of cultivation. Site AJL3: An abandoned Jhum fallow (3 years) that was exposed to a similar cycle of cultivation as JL. Site AJLB: An Abandoned Jhum land (3 years) that has completed its 3rd cycle of cultivation. This site employs the traditional technique of introduction of bamboo stands with the onset of the fallow period (*Bambusa tulda* Roxb.). Site AJL12**:** An Abandoned Jhum land in its 12 years of fallow. Next, two economically viable *Musa* cultivars were selected for plantations at the sites *viz*., *Musa* cultivar 1: Aot Mungo (Ao Naga) and *Musa* cultivar 2: Atsu Mungo (Ao Naga). The goal of introducing the cultivars was to understand the effect of the fallow period on the agronomic performances and proximate composition of the banana cultivars. As banana is vital for the livelihood security of the region, it is crucial to understand the

effects of the various land use on its productivity. It is therefore crucial to assess, monitor and maintain the soil quality in the region. Hence the research work entitled *"**Agro-ecological studies on two selected Musa cultivars planted in cultivated and abandoned Jhum land of Mokokchung District**"* was taken up with the following objectives:

1. To compare the agronomic traits of two *Musa* cultivars.
2. To estimate some selected biochemical composition of the *Musa* cultivars.
3. To compare the seasonal variation in physico-chemical parameters of soil.
4. To compare the diversity and population of rhizospheric soil fungi associated with *Musa* in both abandoned and cultivated Jhum land.

The following hypothesis was proposed to justify the effect of shifting cultivation and fallow on soil quality, agronomic performance, and proximate composition of the selected *Musa* cultivars, and rhizospheric soil fungi associated with *Musa* in both abandoned and cultivated Jhum land.

1. Shifting cultivation and length of fallow period affect soil quality.
2. Shifting cultivation and fallow length alter the agronomic performance of *Musa* cultivars.
3. Shifting cultivation and fallow length alter the proximate composition of *Musa* cultivars.
4. Shifting cultivation and fallow length affect the rhizospheric fungal diversity and population of *Musa* cultivars.

Chapter-2 of the thesis explains the various materials and methods utilized in the study. For soil analysis, soil samples were collected layer-wise at a depth of i.e. 0-10cm, 10-20cm, and 20-30 cm. For physico-chemical analysis, methods proposed by Kjeldahl method (1883), Walkley and Black (1934), Piper (1942), Bray and Kurtz (1945), Bower *et al.* (1952), Misra (1968), Jackson (1973), Trivedy and Goel (1986), and Allen (1989) were used. Soil quality index was obtained by utilizing the Additive quality index (Nabiollahi *et al*., 2017) and Weighted quality index (Raiesi, 2017). To determine the agronomic performance of the two *Musa* cultivars, the suckers were first screened and planted as per Tumuhimbise and Talengera (2018) and Uwimana *et al*. (2020). Suitable agronomic traits were selected from the method proposed by IPGRI-INIBAP/CIRAD (1996), Hauser and Van (2010), Biswas *et*

al. (2017), and Uwimana *et al*. (2020). Both the fruit pulp and peel of the two selected *Musa* cultivars were analyzed for their proximate composition as per A.O.A.C (2000). To determine fungal diversity, soil samples were collected seasonally from random rhizospheric region and cultured in Rose Bengal Agar and Potato Dextrose Agar media (Selman and Waksman, 1921; Waksman, 1922) and maintained. The fungi were identified by using literature (Gillman, 1957; Watanabe, 2002; Ho *et al*., 2003; Hauser, 2006; Nagmani *et al*., 2006; Webster and Weber, 2007; Afzal *et al*., 2013). Percentage contribution was recorded as per Salve *et al.* (2019). Diversity indices were recorded as per Simpson (1949), Pielou (1969), and Berger (1976). A Canonical Correspondence Analysis (CCA) was performed as per Marín *et al*. (2017) and Liu *et al*. (2016) to study the effect of season and soil properties on fungal distribution. Lastly, Phosphate solubilizing fungi were screened as per Premono *et al.* (1996).

Chapter-3 of the thesis deals with the assessment of soil quality in JL, AJL3, AJLB and AJL12. The finding of the soil physico-chemical properties highlights the degradation of soil at JL with elevated BD, reduced SOC, nutrients, and clay content as compared to AJL3, AJLB and AJL12. The introduction of bamboo in fallow significantly increases EC, SOC, N_{av}, Moisture, clay, CEC, TN, and reduced the BD levels. The result of the Principal Component Analysis (PCA) accounted for a total variance of 79.97% at JL, 80.26% for AJL3, 77.14% at AJLB and 72.47% at AJL12. The creation and selection of MDS for each site also highlight the degradation of soil at JL. At JL, CEC, BD and clay are retained; at AJL3, SOC, moisture and pH; at AJLB, SOC and P_{av}; at AJL12, SOC and moisture are retained. These MDS represent the key soil variable of each sites. The additive index (SQI_a) was in the order JL<AJL3<AJLB<AJL12. The values were reported as 0.79 (0-10 cm), 0.78 (10-20 cm) and 0.72 (20-30 cm) at JL; 0.81 (0-10 cm), 0.82 (10-20 cm) and 0.79 (20-30 cm) at AJL3; 0.94(0-10 cm), 0.92 (10-20 cm) and 0.91 (20-30 cm) at AJLB and finally, 0.92 (0-10 cm), 0.91(10-20 cm) and 0.89 (20-30 cm) at AJL12. For the weighted index, SQI_w it was in the order JL<AJL3<AJLB<AJL12. The values were reported as 0.68 (0-10 cm), 0.67 (10-20 cm) and 0.63 (20-30 cm) at JL; 0.73 (0-10 cm), 0.73 (10-20 cm) and 0.71 (20-30 cm) at AJL3; 0.79 (0-10 cm), 0.78 (10-20 cm) and 0.76(20-30 cm) at AJLB; 0.82 (0-10 cm), 0.81 (10-20 cm) and 0.79(20-30 cm) at AJL12, respectively. Further, the utilization of both the weighted and additive SQI demonstrates that the weighted SQI is better suited for soil quality monitoring under the region. The result of the chapter is in affirmation of our first hypothesis of "Shifting cultivation and length of fallow period affect soil quality".

Chapter-4 of the thesis deals with the study of the agronomic performance of the selected *Musa* cultivars at the different sites. The present study reports that both *Musa* spp. flower quicker, possess more functional leaves, sucker, and yield at AJLB and AJL12 as compared to JL and AJL3. Aot Mungo displayed a significantly reduced number of plant cycle at AJL12 (491.33±53.42 days) and AJLB (440.67±20.67 days), increased sucker at AJL12 (4.33±0.94) and AJLB (3.67±0.47), and elevated relative yield i.e. AJL12 (99.99±3.24) and AJLB (90.25±2.32). Similarly, for Atsu mungo, the present study report on the significant positive effect of fallow and bamboo on its agronomic traits. The cultivar displayed lowered plant cycle at AJ12 (435±24.91 days) and AJLB (461±39.82 days), higher suckers AJL12 (4.6±1.24) and AJLB (3.66±0.47), and higher relative yield AJL12 (100±2.72) and AJLB (84.63±2.72). We further report that of all the various traits, the plant girth (p=.041), plant height (p=<.001), number of fruits (p=<.001), and number of hands (p=.006) were reported to be significantly higher under Aot Mungo as compared to Atsu Mungo. The generation of critical limits of soil quality indicators for both *Musa* spp. displayed that all soil parameters were under the "Adequate category" for sites AJLB and AJL12. Meanwhile, it is reported that EC values are under the low category for Aot Mungo, while all soil parameters (expect for pH at AJL3 which is in the adequate category) were under the "Moderate category" in JL and AJL3. For Atsu Mungo, a similar observation is reported where all soil parameters were under the moderate category for JL and AJL3. The exception to this was observed for pH and clay at AJL3, which were under the adequate category. As a result, both *Musa* spp. display decreased agronomic performance at sites JL and JL3 when compared to sites AJLB and AJL12. The result of the chapter is in affirmation with our second hypothesis of "Shifting cultivation and fallow length alter the agronomic performance of *Musa* cultivars."

Chapter-5 of the thesis examines the proximate composition of *Musa* cultivars at the different study sites. From the result of the proximate composition of Aot Mungo, the present study reports that shifting cultivation and fallow significantly affected the proximate composition of the fruit. The findings depict that there is increased protein content under a higher fallow period (AJL12) and lower protein at JL. Similarly, moisture content was observed to be highest at AJL12 as compared to no fallow or reduced fallow i.e. JL, AJL3 and AJLB. The highest ash content was also reported to be highest in the raw peel (10.10%) highlighting the high nutrient potential of the underutilized fruit component i.e. peel. A significant reduction in crude fibre content was also observed with the introduction of fallow.

Meanwhile, crude fat content was lowest at JL (0.52%) in the ripe pulp content and highest at AJL12 in the raw peel (6.37). The execution of a Pearson's correlation test to examine the relationship between soil and proximate composition also displayed the positive relationship between ash content and P_{av} levels (r=0.597), and the relationship between silt and protein (r=0.596) content under Aot Mungo. The agronomic performance of the cultivar Atsu Mungo displayed that protein content was highest at AJL12 and lowest at JL. Moisture content displayed a similar trend with the highest value at AJL12 and lowest at JL. Higher ash content was also reported under the peel components as compared to the pulp components, highlighting the high mineral content in the cultivar. Variation in crude fibre, crude fat and total carbohydrate content with implementation of fallow was also observed. The findings report on the positive correlation between ash content and K_{ex} (r=0.514), and ash and soil P_{av} levels (r=0.628). Therefore this result is in agreement with the third hypothesis "Shifting cultivation and fallow length alter the proximate composition of *Musa* cultivars."

Chapter-6 of the thesis examines the rhizospheric fungal diversity from the two selected *Musa* cultivars. A total of 36 fungal species were isolated under the rhizospheric soils of *Musa* cultivars during the present study. The highest occurring genera during the study period were recorded belonging to *Aspergillus* spp. and *Penicillium* spp. At site JL, a total of 19 fungal species were reported under the rhizopshere region of the two selected *Musa* cultivars. The present study reports that *Penicillium* sp. 1 and *Aspergillus* sp. 1 had the highest percentage contribution (10.50%), meanwhile, lowest contribution was recorded belonging to the *Absidia* sp. (0.72%) and *Fusarium* sp. 1 (0.36%). At site AJL3, total fungal diversity was recorded to be 25. Highest percentage contribution was recorded belonging to *Penicillium citrinum* (11.63%), meanwhile lowest was recorded belonging to *Fusarium* sp.1 (0.314%), and *Penicillium* sp. 1 (0.94%). At AJLB, a total of 30 fungal species were isolated. Highest percentage contribution was recorded belonging to *Penicillium* sp. 4 (8.88%), meanwhile lower values were recorded belonging to *Aspergillus candidus*, *Aspergillus versicolor*, *Fusarium* sp. 1 and *Penicillium* sp. 4 (0.95%). At AJL12, a total of 32 fungal diversity was recorded. Highest percentage contribution was recorded belonging to *Aspergillus flavus* (5.54%) and *Aspergillus niger* (5.54%), meanwhile lowest was recorded belonging to *Mucor* sp. 1 (0.79%) and *Humicola* sp. (0.52%). The diversity indices in the present study reported the number of Taxa (S) in the order AJL12>AJLB>AJL3>JL, respectively. The Simpons index of diversity was highest at AJL12 with a value of 0.96, followed by AJLB (0.95), AJL3 (0.94) and lastly JL (0.92). The evenness was maximum at

AJL12 (0.90), followed by AJLB (0.87), AJL3 (0.84) and JL (0.77). Lastly, the Berger-Parker index was highest at JL (0.118) followed by AJL3 (0.116), AJLB (0.089) and lowest at AJL12 (0.055), respectively during the study period. The CCA analysis show that at JL, maximum fungal diversity was reported during autumn, summer and spring and least diversity during winter. Among the soil variable, the present findings indicate that clay content, TN and BD, strongly influenced the fungal diversity. At AJL3, higher fungal diversity was observed during autumn, summer and spring while lower diversity was observed during winter. It was observed that soil variables SOC, BD, clay, pH, K_{ex}, and N_{av} influenced fungal diversity at AJL3. A similar trend was reported at AJLB with maximum fungal diversity during the autumn, summer and spring and least diversity during winter. The present study revealed that BD, silt content, clay, pH, K_{ex}, N_{av}, TN, SOC, temperature and silt content influenced the fungal diversity at AJLB. Lastly, at AJL12, a similar trend of fungal diversity in the order autumn>summer>spring> winter was observed during the study period. Soil factors such as SOC, moisture, K_{ex}, sand and clay content, pH, CEC, N_{av}, TN, temperature and BD influenced the fungal diversity. Lastly, the present study reported a total of 8 fungal isolates with the capacity to solubilize phosphate (PSF). The present study also reports lowest number of PSF at JL (5), followed by AJL3 (6). Site AJLB and AJL12 possessed the maximum number of PSF (7) during the study period. The present study reports higher number of PSF belonging to genera *Penicllium* (3) and *Aspergillus* (2). Therefore, the fourth hypothesis "Shifting cultivation and fallow length affect the rhizospheric fungal diversity and population of *Musa* cultivars" is accepted.

The present study provide crucial information on all the hypotheses proposed and has provided information on the role of unsustainable soil management in determining the soil quality, agronomic performance and proximate composition of the *Musa* cultivars and rhizopsheric fungal diversity. Shifting cultivation is vital for the socio-economic aspect of the ingenious inhabitants of Nagaland. It has strong roots in the cultural domain, therefore its complete eradication may not be possible. However the findings of the research highlight on the negative aspects of the reduction of fallow and increased cropping cycle. The finding of the soil physico-chemical properties highlight the degradation of soil at JL with elevated BD, reduced SOC, nutrients, and clay content as compared to sites AJL3, AJLB and AJL12. The introduction of bamboo in cultivated and abandoned Jhum land significantly increases EC, SOC, N_{av}, Moisture, clay, CEC, TN and reduced the BD levels. The reduced agronomic performance of the two selected *Musa* cultivars at JL predicts the danger of continued

unsustainable means of soil utilization. Such practices must be monitored and enforced by the policy-makers to ensure soil recovery and retention of soil quality. Therefore tools such as the creation of MDS and the implementation of SQI in the region may be utilized to generate soil quality index maps. The data generated from the SQI can be quickly disseminated to the ingenious inhabitant with fewer resources and time spent. Such method will aid in monitoring and policy-making for the stakeholders.

Next, the establishment of the critical limits of soil quality indicators allows for the classification of land best suited for the specific *Musa* cultivar. The construction of such critical limits of soil quality indicators in the region will be valuable in future crop monitoring and evaluation programs and ensure livelihood security. The information from the present study also reports on the significant role of soil in determining the nutrient composition of the selected cultivars. Livelihood security can be achieved only when both quantitative as well as the qualitative needs are sufficiently met. Therefore such information may be adequately disseminated to the policy makers. The negative aspect of unsustainable means of farming (reduced fallow and increased cropping cycle) are also reflected in the rhizospheric fungal population. Anthropogenic disturbances such as firing and monocropping enable specific fungal communities to dominate, making the fungal population disproportionate. The maintenance of fallow leads to increased fungal diversity. The study also reports on the beneficial aspect of bamboo introduction in fallow for the increased fungal diversity. There is also a need for good-quality fungal inoculants to decrease the dependence on chemical fertilizers. Therefore, the PSF screened in the present study may be used for future extensive field experiments to determine their viability. Such vital information should be thoroughly disseminated to the local stakeholders and policymakers to ensure the sustainable utilization of the Jhum land.