SOIL MICROCLIMATIC PARAMETERS AND MICROBIAL ACTIVITIES ON THE POPULATION AND DIVERSITY OF ARBUSCULAR MYCORRHIZAL FUNGI

By

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(2017-11-139)

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VELLANIKKARA, THRISSUR – 680656

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THESIS

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DEPARTMENT OF AGRICULTURAL MICROBIOLOGY

COLLEGE OF HORTICULTURE

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KERALA, INDIA

2019

DECLARATION

I hereby declare that this thesis entitled **"Soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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Introduction

1. INTRODUCTION

Arbuscular mycorrhiza is a mutually beneficial association between the plants of terrestrial ecosystem and mycorrhizal fungi belonging to the phylum Glomeromycota. Arbuscular mycorrhizal fungi (AMF) are widely distributed and act as one of the critical microbe for plant growth (Smith and Read, 1997). Mycorrhizal association on plant root causes numerous changes in metabolic and enzymatic activity in plant as well as rhizospheric soil. Mycorrhizal fungi are considered as an important link, that connecting above and below ground processes. Mycorrhizosphere modify the microbial ecosystem and support the growth and development of host plants.

Arbuscular mycorrhizal fungi is an important soil microbe, as they can affect the various ecosystem functions. Different AMF community assist the host plants in absorption of nutrients like P, N, K, Zn, Fe, Cu and water. Arbuscular mycorrhizal fungi are ecologically and economically important as they can mitigate several abiotic stresses such as mineral toxicity, acidic pH of soil and drought stress. AMF also help to reduce the impact of different biotic stress like disease incidence and nematode infection.

The impact of global climate changes are visible in wide variety of sectors in ecosystem. The climatic parameters have a great importance in determining soil physico- chemical parameters and other soil properties. Soil microbial ecosystem and their activities vary with soil characteristics, plant properties and climatic condition. Several soil parameters such as soil temperature, soil moisture, soil pH and nutrient availability exhibits their role in determining the diversity, distribution and activity of soil microorganisms including AMF. The studies on mycorrhiza are important to understand the effect of global change on ecosystem, due to their key role in plant-soil interface. Moreover, AMF mediate the response of plant and ecosystem to climate change.

The arbuscular mycorrhizal fungi are obligate symbiont, which need a host for its survival. *Solenostemon rotundifolius* or Chinese potato is one of the important minor tuber crop cultivated in south India, especially Kerala. It is commonly known as '*koorka*' in Malayalam. Tubers of Chinese potato are rich source of starch, proteins, vitamin A, thiamine, vitamin C, phosphorus, potassium, calcium and iron. *Solenostemon rotundifolius* is reported with 70-90% of mycorrhizal dependency (Potty, 1990b). Biomass production of coleus plant also increases with mycorrhizal association, due to enhanced nutrient uptake. In addition, the antagonistic effect of arbuscular mycorrhizal fungi on root knot nematode, an important pest of Chinese potato has also been reported. So, there is an immense scope in selection of a suitable AMF for enhanced growth and healthy tuber production of *Solenostemon rotundifolius*. There is also a need to study the soil microclimatic factors and microbial activities on the AMF population and diversity in the rhizosphere of Chinese potato plant.

However, no work has been carried out on the effect of different soil microclimatic variables and microbial activities on AMF, under tropical humid climatic condition in a lateritic soil with low pH such as in Kerala. Hence, the present study was undertaken on "Soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi" with following objectives:

- To study the effect of soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi.
- To evaluate the effect of AMF on the growth and yield of Chinese potato (*Solenostemon rotundifolius*).

Review of literature

2. REVIEW OF LITERATURE

2.1 MYCORRHIZA AND ARBUSCULAR MYCORRHIZAL FUNGI (AMF)

Mycorrhizae are one of the very important and critical microbe for plant growth and survival (Smith and Read, 1997). The term “mycorrhiza” is derived from two Greek words “mycos” and “rhizome”, which means fungus and root respectively. It is a beneficial association between roots of higher plants and fungus, as a mutualistic or symbiotic biotrophy. Arbuscular mycorrhizal fungi have been reported from the Devonian gametophytes of 400 million years ago (Taylor et al, 1995; Phipps and Taylor, 1996). Theodore Hartig was the first person who described mycorrhiza, but did not examined its function. Later, in 1885, Frank introduced the term mycorrhiza and explained the role of mycorrhiza on the growth of plants (Singh *et al*., 2009).

Mycorrhizal fungi and their extraradical mycorrhizal hyphae (EMH) contribute about 20- 30% of soil microbial biomass (Leake *et al*., 2004). Based on the physical relationship of fungus and host root cells, mycorrhiza are classified in to three main groups namely, ecto, endo and ectendo mycorrhiza. Ectomycorrhiza produce hartig net between cells and fungus mantle or on the surface of feeder roots. Fungi invade cortical cells of feeder cells produces the absorbing hyphae called arbuscules and swollen food storing hyphal swelling called vesicles are familiar in most of endomycorrhiozal fungi, hence they are termed as vesicular arbuscular mycorrhizal fungi (Singh *et al*., 2009).

The arbuscular mycorrhizal fungi (AMF) are an ancient asexual group of eukaryotes, which separated from the other fungal lineages over 600 million years ago. The presence of non-septate hyphae, vesicles, arbuscules and clamydospores in silicified roots of the Triassic cycad (*Antarcticycas schopfii*) was the earliest reliable evidence for AMF in seed plants

(Stubblefield *et al*., 1987; Phipps and Taylor, 1996).

More than 80% of vascular plants are associated with AM fungi (Smith and Read, 2008). AM fungi associations were reported from almost all terrestrial ecosystems. AM fungi are obligate biotrophs and they require roots of living host to grow and complete their life cycle. Synthetic medium, which can support the full proliferation of AM fungi in absence of living host is not formulated till date (Hildebrandt *et al*. 2002). Host specificity of AMF is not thoroughly understood (Anderson, 1988). But, it rely upon the host plant (Lackie *et al*., 1988).

2.1.1 Importance of AMF

The symbiosis of arbuscular mycorrhizal fungi gather wide range of benefits to host plants in agricultural production system and natural ecosystem (Tanwar *et al*., 2014) by assisting in mineral uptake and combat different abiotic and biotic stresses (Barea *et al*., 1993).

According to Marschner and Dell (1994), VAM provided up to 80% of plant P, 25% plant N, 10% plant K, 25% plant Zn and 60% plant Cu through the external hyphae.

Potty (2005) reported that, the cassava plants inoculated with mycorrhizal fungi had high P (35-45%), Zn (11%) and Cu (6-9%) content than non- mycorrhizal plants.

AMF inoculation improved the concentration and uptake of P, Fe and Zn in wheat, however mycorrhizal symbiosis in faba bean did not show significant effect on P concentration and uptake (Ingraffia *et al*., 2019).

Zarea *et al*. (2011) reported that, in AMF inoculated plants nitrogen concentration and nitrogenase activity were high. The activity of AM fungi increased N mass contained in plants by 50%, which led to a decreased N availability to heterotrophs in this nutrient-poor soil (Langley *et al*., 2005). According to Wilson *et al*. (2009) there was a positive correlation between hyphal abundance of AMF, soil aggregation and C and N sequestration.

AMF not only supported in nutrients absorption, but they also helped the plants to survive under mineral toxicity situation in soil. There was a wider range of difference in the AMF isolates for plant grown in pH 4 and 5, and lower level of Al acquisition was from the mycorrizal plants compared to non- mycorrhizal ones in both pH. *Glomus clarum* and *G. diaphanum* were more effective for minimizing the effect of acidic soil in switchgrass (Clark, 1997). Elahi *et al*. (2012) reported that AMF inoculation minimized arsenic toxicity and promoted the plant growth and nutrient absorption of N, P, K and S in chili plants.

Rohyadi *et al*. (2004) observed that, mycorrhiza supported plants to survive under highly acidic condition. It is reported that there was a positive correlation between increased root colonization by *Gigaspora margarita* with increased growth response of the cowpea plants under different pH ranges.

Decline in the disease severity and nematode infection in the AMF inoculated plants was reported by Veresoglou and Rillig (2011). They recorded a reduction of 30 to 42% fungal and 44–57% nematode pathogens compared to control. In their study, *Glomus mosseae* was found as the most effective among the inoculants.

AMF improved the resistance of host plants against soil borne pathogen attack. Song *et al*. (2015) reported that, mycorrhizal inoculation with *Funneliformis mosseae* significantly decreased early blight disease caused by *Alternaria solani* Sorauer in tomato (*Solanum lycopersicum* Mill.). Disease incidences and indices reduced by 54.3% and 72.8% respectively. AMF pre-inoculation led to significant rise in the activities of defense-related enzymes like β- 1, 3- glucanase, chitinase, phenylalanine ammonia- lyase (PAL) and lipoxygenase (LOX) in tomato leaves upon pathogen inoculation.

Funneliformis mosseae protected wheat plants from powdery mildew

disease caused by foliar biotrophic pathogen *Blumeria graminis* f. sp. *tritici*. The infection was reduced by 78% in mycorrhizal plants, compared to non-mycorrhizal (control) plants (Mustafa *et al*., 2017).

Saraswati *et al*. (2012) conducted an experiment of the influence of AMF in drought tolerance in sweet potato plant. The mycorrhiza inoculated plant exhibited higher value of leaf relative water content, root dry weight, root length, transpiration and water use efficiency as compared to non AMF plants. They also found that AMF was effective in enhancing the drought stress tolerance in sweet potato. Abdel-Salam *et al*., (2018) also observed the performance of mycorrhizal plants under drought stress condition. Majority of growth, nutrition, water status and photosynthetic parameters of plants had a great dependency on the mycorrhizal colonization under all levels of drought stress.

2.1.2 Taxonomy of AMF

Symbiotic association between a fungus and root has been discovered in *Monotropa hypopitys* L. by Franciszek Kamienski (Kamienski, 1881) and term "Mycorrhiza" was coined by Frank in 1885 (Frank, 1885). However, the fungi vesicular arbuscular mycorrhiza (now Arbuscular Mycorrhiza) were described much earlier. Classification of Glomeromycota started during 1809. First description on AM fungi has been published by Tulasane brothers by describing the genus *Glomus* and later transferred it to *Endogone* (Tulsane and Tulsane, 1845). The genus Endogone was very large and it was difficult to distinguish between species. A revision was made by Gerdemann and Trappe (1974) with sporocarps and mycorrhizal infection as criteria of classification and it led to formation of seven genera. Sporocarpic chlamidospore forming endogone species were segregated in to *Glomus*. The genus *Endogone* was revised and described in to two new genera *Acaulospora* Gerdemann and Trappe emend. Berch and *Gigaspora* Gerdemann and Trappe emend.

Ames and Schneider (1979) described new genus *Entrophospora* Ames

and Schneider emend., by separating it from genus *Acaulospora* based on the mode of spore formation. New genus *Scutellospora* was introduced by Walker and Sanders by separating from genus *Gigaspora* based on wall characteristics, mode of spore germination and auxillery cells. Pirozynsky and Dalpe (1989) separated six mycorrhizae forming genera into family Glomaceae and non mycorrhizae forming family Endogonaceae. A manual with species description was introduced by Schenck and Perez in 1990. Based on morphological characteristics of reproductive structures like spores, somatic structures (hyphae, arbuscules and vesicles), ontogeny and spore germination, Morton and Benny (1990) classified AMF into a new order Glomales. But, the class of AMF was not explained. Fungi forming arbuscular mycorrhizal association with plants were placed in a new class called Glomeromycetes in a new phylum Archeomycota (Cavalier-Smith, 1998).

Classification of AMF by using only morphological characters of AMF spore was limited. Redecker *et al.* (2000) utilized both morphological and molecular data and transferred *Sclerocystis coremioides* to the genus *Glomus.* Morton and Redecker (2001) introduced two new families in the order Glomales (now Glomerales) *i.e*., Archaeosporaceae and Paraglomaceae (now Paraglomeraceae), based on molecular, morphological and biochemical characters.

According to the new system for arbuscuar mycorrhizal fungal taxonomy, three classes (*Archaeosporomycetes, Glomeromycetes,* and *Paraglomero-mycetes*), five orders (*Archaeosporales, Diversisporales, Gigasporales, Glomerales*, and *Paraglomerales*), 14 families, and 29 genera are recognized. Key anatomical and morphological features were characterized by the molecularly supported taxa (Oehl *et al*., 2011).

2.2 CHINESE POTATO (*Solenostemon rotundifolius*)

Solenostemon rotundifolius [(Poir.) J. K. Morton] or *Coleus parviflorous. Benth* belonging in Lamiaceae family, popularly known as

Chinese potato. It is an important tropical crop cultivated in various parts of Africa and Asia for its edible tubers. Coleus also known as Hausa potato, Zulu potato, Sudan potato or frafra potato in English and koorka in malayalam. It is an annual herbaceous plant, having duration of four to five months, with ascending or prostrate stem and thick leaves having aromatic smell.

It is believed to have originated from Central or East Africa but spread throughout tropical Africa and into South-east Asia. Young plants are greenish or reddish in color. The tubers may be with black, red or white-yellow skin and white, white- yellow or yellowish flesh depending upon the morphotypes. Tubers are oblong or ovoid in shape. Tubers are rough and some produce lateral tubers (Nanema *et al.*, 2017).

Chinese potato tubers are good source of starch (about 16% of tuber weight) (Jayakody *et al*., 2005). Moisture content of pulp was higher (79%) than waste (61%). Tubers are rich source of carbohydrates. The maximum amount of carbohydrate was observed in pulp sample (85%) with high amount of protein in waste (15.2 mg/ 100 g) than pulp (13.6 mg/ 100 g). Reducing sugar content in Chinese potato pulp was 26 mg/ 100 g and non-reducing sugar about 8.24 mg/ 100 g. The crude fat and crude fiber were observed highly in pulp (1.2%) and in waste (4.8%). The tuber material contained vitamin A, thiamine, vitamin C, phosphorus, potassium, calcium and iron (9.9 mg). Pulp was mainly used for cooking purpose to yield 392 calories per 100 g (Priya and Anbuselvi, 2013).

Tubers of Chinese potato are used as an essential dietary and energy source during the lean periods. It can be consumed as a main starchy staple food or in combination with cereals or vegetables, as in boiled, baked or fried forms (Schipper, 2000; Wulueng *et al*., 2000). Leaves of chinese potato has the ability to cure dysentery, and also used in rural areas of Nigeria (Tindall, 1983) and preparation of boiled leaves also used against disorders such as blood in urine and eye disorders including glaucoma (Schipper, 2000;

Irvine, 1990).

2.2.1 Effect of AMF on Chinese potato

Glomus microcarpum var. microcarpum, Gigaspora nigra and *Selerocystis* sp were common in coleus. (Potty, 1990a). Mycorrhizal dependency in coleus was 70 to 90% (Potty, 1990b).

Potty (1990a) reported that, significant mycorrhizal infection in coleus plants were observed after 15 days of inoculation with *G.microcarpum* spores (stored for six months at 21°C). There were more mycorrhizal roots at low fertility than at high fertility. Although plant growth was better at high fertility, the development of inoculated plants were always better than that of the non-inoculated plants. Number of branches, weight of the shoot and root were higher in AMF inoculated coleus plants compared to non-VAM plants in both high and low fertility treatments.

VAM inoculation by the use of lignite- slurry (Potty, 1990c) converted the major part of root system into mycorrhizal roots in Chinese potato. The percentage of AMF infection increased at three different stages. An infection of 10- 45% was observed in the first phase of development which is 15 to 30 days after inoculation. From 30 to 75th day was the phase of rapid spread, which showed 45 to 80% colonization. The third phase was noticed from 75 to 95th day with a decline of growth and colonization was 80 to 85% only (Potty, 1982).

Sreekumar (2000) conducted survey in many parts of Chinese potato growing areas in Tamil Nadu and Kerala, and revealed the presence of more than one AM fungal species association in the root system. Samples collected from in and around Thiruvananthapuram in Kerala state showed highest per cent root colonization (60 - 80%), but in Tamilnadu it was 12 - 16%. The high incidence in Kerala soils indicated the influence of different soil and environmental factors, including chemical composition of the soil, pH of the

soil, soil moisture and the cultivation practices. Among the isolates identified, incidence of *Glomus microcarpum var. microcarpum* (SRAM9) was maximum, from six locations followed by *Glomus mosseae* and *Glomus fasciculatum* from five location each. The higher concentration of chlorophyll a and chlorophyll b in mycorrhiza inoculated Chinese potato plants showed the increased photosynthetic fixation of CO_2.

2.3 EFFECT OF SOIL PARAMETERS ON AMF

Effect of different soil parameters like soil temperature, soil moisture, soil pH, soil type and soil nutrient status on AM fungal characters such as root colonization, spore density and diversity were reported.

2.3.1 Effect of soil temperature on AMF

2.3.1.1 Effect of soil temperature on root colonization by AMF

According to Schenck and Smith (1982), optimum temperature for root colonization by Arbuscular mycorrhizal fungi were depended upon the species of AMF. *Glomus datum, Glomus claroideum, Gigaspora pellucida, Gigaspora gregaria* and *Acaulospora laevis* were showed maximum root colonization and sporulation at 30^0C. Maximum root colonization for *Gigaspora gregaria* and *Glomus mosseae* were observed at 36^0C and 24^0C respectively.

In a field experiment on effect of artificial warming on AMF by using infrared heaters, conducted by Rillig *et al*. (2002) found that, increase in the soil temperature increased the AMF root colonization and enhanced the length of AMF hyphae in soil by 40%.

Gavito *et al*. (2003) found that, very low temperature reduced the hyphal proliferation in soil. While increase in temperature from 10^0C to 15^0C in Denmark, showed a corresponding increase in intra radical root colonization from 40 to 71%. At 10^0C, no extra radical hyphae were observed, and showed poor development at 15^0C.

Heinemeyer and Fitter (2004) studied the effect of warming in both the plants and mycorrhiza. They observed an enhanced growth response of the extraradical mycelium (ERM) to temperature, independent of plant biomass in the order of *G. mosseae* >*G. hoi* >*Acaulospora* sp. Length of colonized root (LRC) and extraradical mycelium (LERM) declined after initially peaking between 33 and 40 DAP (<10%). LRC and LERM increased over time and total LRC was nearly three times and LERM almost twice as large under the higher temperature. On the last day of sampling, there was no significant effect by temperature on ERM of any of *Glomus* spp. but it was more evident (not significant) in *Acaulospora* sp.

Gavito *et al*. (2005) reported that, the total root length increased linearly from 6 to 24°C in the three temperature treatments tested for *Glomus cerebriforme*. The highest temperature (30°C) increased the root length colonized by *G. intraradices*, but decreased it in *G. proliferum* cultures.

According to Hawkes *et al*. (2008), the distribution of the mycelial network, vesicles formation and extra-radical mycelium were significantly affected by the temperature. At low temperature hyphal density reduced and vesicles formation increased. But the pattern of AMF colonization and hyphal growth were depended on environmental condition, where the growth of hyphal networks enhanced in warmed soils and a mixed strategy of growth and storage exhibited in ambient soils. More vesicles in cooler soils indicated that the fungus survives through periods of poor growth conditions. Rise in soil temperature caused an increase in the spread of the extra radical AM hyphal network, fastened the speed of plant photosynthates transfer and AM fungal respiration. At high temperature carbon storage by AM fungi was less, and a rapid return of plant carbon to the atmosphere through AM fungal respiration were observed with an enhanced release of carbon per unit of hyphal length.

Wilson *et al.* (2016) studied the effect of warming on AMF

colonization by providing heat through the combination of a greenhouse experiment and a manipulative climate change experiment embedded within a Mediterranean climate gradient in the Pacific Northwest, USA. They found warming directly decreased AMF root colonization.

Felenou *et al*. (2017) reported that the correlation between the rate of colonization and the temperature was low and negative. Bhardwaj and Chandra, (2018) also had the same result, root colonization was negatively correlated with increase in temperature.

2.3.1.2 Effect of soil temperature on AMF spore count

As per the reports from different studies, besides the effect of soil temperature on root colonization, the relationship between soil temperature and AMF spore count were also noted. AMF spores isolated from the rhizosphere of two fruit trees *Paullinia cupana* and *Theobroma grandiflorum*, were significantly correlated with maximum temperature (Oliveira and Oliveira, 2010).

Wheat rhizosphere study conducted at regions around Jhansi by Panwar *et al*. (2011) showed that, there was an increase in spore density with temperature and maximum spore count was during summer than winter. Optimum temperature for AMF growth recoded as 20.80- 28.79^{0}C.

Gaur and Kaushik (2012) assessed the effect of seasonal variation on mycorrizal fungi in the medicinal plants of Himalayan region. They reported that monthly and seasonal variation had significant effect on fungal population. Higher temperature in the month of May- June (25-40^{0}C) reduced AMF spore count, but during Jan- Feb (6-22^{0}C) and Sept- Oct (20-25^{0}C) favored spore population.

Sivakumar (2013) reported that, spore density was highest during summer (378.79/100g) and lowest during winter (222/ 100 g) in the rhizosphere soils of sugarcane crop collected from 14 different regions in Pudukkottai district, India. Altogether, 23 AM fungal species belonging to

four genera, namely, *Acaulospora*, *Gigaspora*, *Glomus*, and *Scutellospora* were isolated from the study sites. Both *G. mosseae* and *G. fasciculatum* were found as dominant species with a distribution frequency of 92.8.

Parkash and Saikia (2015) noticed that, AM fungal spore density decreased with increase in temperature and arbuscules were present only at lower temperature, at 20^0C.

Zhang *et al*. (2016b) reported that elevated temperature decreased AMF spore density and diameter by 32% and 10% respectively, but increased the hyphal length density (HLD) by 27%. They also found that, composition of AMF spore population was not affected by rise in temperature. But, according to Bhardwaj and Chandra (2018) population of AMF spore increased with increase in soil temperature.

2.3.1.3 Effect of soil temperature on AMF population and diversity

According to Sun *et al*. (2013), artificial warming significantly decreased the AMF species diversity. The performance of different AMF species was dependent on their ability of sporulation. The AMF community with higher spore abundance performed better under higher temperature than rarely or little sporulating AMF community.

Asha *et al*. (2017) studied the AMF spore abundance and diversity at different temperature and CO_2 levels and found that, spores of *Glomus fasciculatum* were dominant at elevated CO_2 plus temperature. Highest Shannon diversity index and species richness were recorded from elevated CO_2 and temperature treatment (3.10), followed by elevated temperature (2.37) and ambient condition (1.37).

2.3.2 Effect of soil moisture on AMF

2.3.2.1 Effect of soil moisture on root colonization by AMF

Soil moisture had an effect on the AMF root colonization on plants and formation of different hyphal structures. Miller (2000) reported that the

plants like semi-aquatic wetland grasses, such as *Panicum hemitomon* and *Leersia hexandra* have a negative correlation between relative water depth and proportion of root length colonized by AMF. The ratio of vesicles: hyphae was very low, and arbuscules were major proportion of total colonization in the wet plots. Less than ten percent colonization was observed in the saturated treatments.

The studies conducted by Prasad and Mertia (2005) also reported negative correlation between root colonization by AMF and moisture. Irrigation had reduced root colonization by 14.2% in the agroforestry trees at arid zone of India.

According to Oliveira and Oliveira (2005), soil moisture content was positively correlated with colonization and they also noted that during rainy season the mean percent colonization of AMF reached highest values.

A low positive correlation between moisture and host root colonization was reported by Parkash and Saikia (2014) and Felenou *et al.* (2017). The significant positive correlation of AMF root colonization with soil moisture was explained by the enhanced plant growth due to heavy root colonization in rainy season as compared to summer season. Tree plantations of *Millettia pinnata* and *Peltaphorum ferrugeinum* showed strong positive correlation with root colonization by AMF and soil moisture. However, *Azadirachta indica* showed comparatively poorest r^2 value of 0.4871 (Bhardwaj and Chandra, 2018).

2.3.2.2 Effect of soil moisture on AMF spore count

Studies conducted by Oliveira and Oliveira (2005) noted that, the highest AMF spore count were recorded during the rainy season (April - May in 1999 and February- May in 2000).

According to Prasad and Mertia (2005), the AMF spore abundance varied based on physico-chemical properties of soil, moisture as well as on vegetation cover. Soil moisture exhibited a negative correlation with AMF

spore count in the soil and irrigation reduced AMF spore abundance by 16.2%. Smith and Read (2008) also reported that, water availability increased fungal mycelium growth for root colonization in wet soil and led to a decreased spore germination.

Oliveira and Oliveira (2010) reported that, there was significant and positive correlation existed between the precipitation and AMF spore numbers for the two fruit species *Paullinia cupana* and *Theobroma grandiflorum*. The study showed that the climatic variable was responsible for of the increase in AMF spores in the rhizosphere of *P. cupana* and *T. grandiflorum* by 87 and 84% respectively. Similarly a significant positive correlation was observed between soil moisture content and AMF spore population (Khanam *et al*., 2006 and Kumar *et al*., 2010).

Ndoye *et al*. (2012) analyzed the AMF spore characters and enzymatic activities in the rhizosphere soil of *Acacia senegal*, a legume tree. It was found that AMF spore diversity and density were high in the soil collected from the dry region as compared to wet region. Gaur and Kaushik (2012) also got a similar result, higher humidity and moisture reduced AMF spore density in Himalayan regions. AMF population was negatively correlated with moisture content (Shukla *et al*., 2013)

The studies conducted by Bhardwaj and Chandra (2018) on the variation of spore population with soil moisture in the tree plantation in entisol soil showed that, there was a negative correlation between spore population and soil moisture. Spore population also varied with season. Highest spore population was recorded in the beginning of summer (March-April) and least at the spring season (December).

2.3.2.3 Effect of soil moisture on AMF population and diversity

Khade and Rodrigues (2004) conducted a study on the influence of monsoon on AMF spore count in soil. Spore density of AMF was maximum in pre-monsoon with 426 spores per 100 g soil, followed by monsoon (384

spores per 100 g soil) and least was in post-monsoon season (250 spores per 100 g soil). There was a variation in species richness during different seasons. Seven species of AMF belonging to three genera *viz., Acaulospora, Glomus,* and *Sclerocystis* were isolated. The species richness of AMF was maximum during pre-monsoon (seven species) and minimum during post-monsoon season (four species).

According to Torrecillas *et al*. (2013), diversity and richness of terrestrial AMF communities were positively correlated with precipitation. But, there was no significant correlation found between climatic variables and AMF richness and diversity on epiphytic AMF communities.

2.3.3 Effect of soil pH on AMF

2.3.3.1 Effect of soil pH on root colonization by AMF

According to Wang *et al*. (1993), the soil pH ranged from 4.5 -7.5 showed only little effect on root colonization and crop yield of spring oat and potato. Only few spores were present at 5.5 and there was no spore observed in highly acidic soil.

Andersson *et al*. (1996) noticed that, mycelial growth of AMF into the substrate was inhibited by liming. However mycorrhizal colonization of the roots were not affected by it.

Sreekumar (2000) conducted a survey in major Chinese potato growing part in Kerala and Tamilnadu. Soil sample collected in and around from Thiruvananthapuram, Kerala with pH ranged from 5.5- 6.8 had high colonization rate, 60- 80%. But the areas of Thirunelveli district where the pH was alkaline (7.2- 8.0) had AMF colonization of 12- 16%.

Kumar *et al*. (2008) reported that AM fungal colonization was high in slightly acidic soils compared to the neutral and alkaline soils. Experiment was conducted in Karnataka, and AM fungal colonization ranged between 26.80 to 68.00 percent. Highest percent root colonization (68%) was

observed in root samples collected from Kolar (pH – 5.43) followed by Bangalore (52%) (pH 6.60), Mandya (50.40%) (pH 6.35) and Hassan (49.80%) with pH 6.22. A least percent root colonization (26.80%) was observed in root samples of Tumkur with pH 7.02.

Parkash and Saikia (2014) observed that percent root colonization by AMF was positively correlated with soil pH.

Ouzounidou (2015) reported that, percentage root colonization was improved by 30% in the plants grown in control and in alkaline soil while compared to the acidic soil in the case of both AMF inoculated and uninoculated plants. Intracellular hyphae were the dominant structures in all roots examined, whereas arbuscules were scarce.

Felenou *et al*. (2017) reported that, pH of study sites did not show significant impact on root colonization and mycorrhizal symbiosis in *Allanblackia floribunda,* a tree in the tropical forest ecosystem.

Acidic and alkaline pH had different influence on root colonization by AMF. Patale (2018) studied the effect of alkaline condition, with pH ranges from 8 to 8.95, and found that alkaline condition favored mycorrhizal spores and root colonization.

2.3.3.2 Effect of soil pH on AMF spore count

Studies by Isobe *et a*l. (2007) showed that, none of the soil samples with a low pH, less than 6 and high pH, greater than 8 had more than 5 spores per g soil. The soil pH range from 6-8 had reported with maximum spore density. In general, the study indicated that, spore germination, hyphal elongation and infection with AM fungi are suppressed on acidic or alkaline soil.

The experiment conducted by Kumar *et al*. (2008) reported that AM spore density per 50 gram of soil was significantly more in the rhizosphere soils collected from slightly acidic areas like Kolar (194) followed by Bangalore (136.8), Tumkur (132.6), Hassan (121.8) and least in case of root

samples from Mandya (120), which had alkaline soil.

Shukla *et al*. (2013) studied the distribution and diversity of AMF in different soil depths of naturally growing *Withania somnifera* and *Ocimum sanctum* and the correlation analysis revealed a positive correlation of AMF spore population with soil pH.

Bhat *et al*. (2014) observed that, the site with pH 7.45 reported more AMF spores, but further increase in the pH (8.25) recorded less spores. They also noticed a negative correlation between soil pH and AMF spore density.

Parkash and Saikia (2014) observed that, pH ranged from 5.69 to 8.4 promoted AM fungal density. Pearson's correlation analyses of the study showed that, there was a positive correlation between soil pH and AMF spore density (p=0.16)

According to Cibichakravarthy *et al*. (2015), soil pH showed a negative impact on spore abundance and infective propagules of AMF. Both AMF spore density and infective propagules reduced by pH.

Nongkling and Kayang (2017) noticed a significant negative correlation between spore density and soil pH in upland rice grown under mixed and mono cropping system.

2.3.3.3 Effect of soil pH on AMF population and diversity

Soil pH is a significant factor involved in the shaping of AMF community composition. Microbial communities and particularly AMF communities were highly influenced by soil acidity, which is one of the most important drivers or environmental filters (Alguacil *et al*., 2016). Soil pH affected AMF communities significantly (Xu *et al*., 2017).

The studies by Abbott and Robson (1985) showed that, phosphorus uptake and plant growth of subterranean clover increased by inoculation with *Glomus* sp. (WUM 16), but only when soil pH was alkaline (7.0 or higher). At pH levels from 5.3 to 7.5, inoculation with *G. fasciculatum* increased

plant growth.

Species diversity of AMF was highly depended on soil pH. *Glomus mossae* and *Glomus intraradices* isolated frequently from neutral to alkaline soil, whereas species of *Acaulospora* were usually found in acidic soil. Optimum pH for different AMF varied based several factors, but specific species had optimum at which it can perform well (Bhat *et al*., 2014).

Increase in pH and P availability increased spore density. The soils with neutral pH had higher spore density but was poor in spore diversity, where only two types of mycorrhizal genus namely *Glomus* sp. and *Acaulospora* sp. were recorded. Acidic soils were with lower spore density, but had more diverse genus *i.e*. *Glomus* sp, *Acaulospora* sp. and *Gigaspora* sp. contrary, lower soil pH had higher mycorrhizal diversity compared to higher soil pH (Astuti and Cahyani, 2018).

2.3.4 Effect of soil type on AMF population

One of major factor driving AMF assemblages is soil type. AMF species richness varied with sampling sites like plantation, natural sand, and bulk soil depending upon soil types (Ndoye *et al*., 2012).

The highest spore population of *Glomus* sp. was reported in sandy loam followed by laterite clay and lowest in clay loam. Red soil showed a high percentage of spore load and colonization (Potty, 1990b). The predominance of *Glomus* and *Sclerocystis* had been reported from the forest soil of Kerala (Lekha *et al*, 1995).

Studies of Gaur and Kaushik (2012) at Himalayan region showed that mycorrhizal spores were abundant in sandy loam soil followed by clay and loamy soils, and was very less in higher altitude.

Alguacil *et al.* (2016) noticed that, individual soil characteristics had an important role in the development specific composition and structure of AMF community. Some of the soil properties like urease, dehydrogenase,

total carbohydrates, pH, Zn, and Mn were significantly influenced the AMF community distribution in roots and rhizosphere of *Brachypodium retusum*.

Sumathi and Thangavelu (2016) conducted a survey to find out AMF spore population in the rhizospheric soil samples of eight different soil types collected from different banana growing regions of India. AMF density was maximum in clay soil (50.8%), followed by sandy loam (16.3%), sand (17.7%), silty loam (5.6%), silty clay- loam (7.1%), clayey loam (2.1) and minimum in loamy and silty clay (0.2%) soils. 91.1% of isolated AMF spores were belonged to *Glomus* spp., which denoted that it was the most dominating AMF spores in banana plantations.

Soil type influenced spore density as well as the percentage of mycorrhizal colonization of roots. Level of mycorrhizal colonization increased most rapidly in silty sand, the highest level of infection was observed in barley roots in clay soil. Each soil type displayed a characteristic distribution of spore types within a population (Land and Schonbeck, 1991).

Krishnamoorthy *et al*. (2015) compared the AMF spore density in contaminated and non- contaminated soil, and found that spore density was significantly higher in highly contaminated soil. Further study in morphology of isolated spores revealed that *Glomeraceae* family was the most abundant followed by *Acaulosporaceae* and *Gigasporaceae*.

The undisturbed soil (forest) had higher colonization rate compared to disturbed soils. Destruction of propagules caused a negative influence on root colonization. Persistence of AMF in the soil was affected by tillage, since mycorrhizae were concentrated in the upper soil layers (Felenou *et al*., 2017). Inorganic fertilization and conventional tillage using low cost manual tillage such as hand hoe negatively affected numbers of infective AMF propagules.

Glomus sp. and *Acaulospore* sp. were common in all areas, but *Gigaspora* sp. was only found in acidic Alfisol soils (Astuti and Cahyani,

2018).

2.3.5 Effect of soil nutrient status on AMF colonization and diversity

Along with various physical parameters of the soil, nutrient status of soil also plays an important role in AMF colonization and diversity. Low-level P application favored the growth and establishment of AM fungi and there by influenced the photosynthetic fixation of CO_2 in Chinese potato. Enhanced accumulation of carbohydrate and proteins in mycorrhizal plants in response to organic matter amendment accounted to increased photosynthetic fixation of CO_2 and synthesis of protein (Sreekumar, 2000).

Studies by Jansa *et al*. (2014) showed that available soil P had no effect on AMF community profiles. Findings of Cibichakravarthy *et al.* (2015) was different, which showed that, soil available P decreased AMF spore abundance, but had no effect on AMF diversity.

In the field experiment conducted by Zhang *et al*. (2016b), N addition reduced spore population diversity and richness of AMF and suppressed the spore density and the hyphal length density (HLD). Addition of phosphatic and nitrate fertilizers reduced AMF spore count and hyphal colonization *via* inducing deleterious effect in AMF life cycle (Verzeaux *et al*., 2017).

Alguacil (2016) reported that, Zn and Mn significantly influenced the AMF community distribution in roots plus rhizosphere of *Brachypodium retusum*.

According to Patale (2018), low phosphorus and potassium levels favored more AM fungal spore in soil. Similarly, soils with minimum levels of copper, zinc, iron and manganese were favorable for the occurrence and distribution of more AM fungi. High iron levels also favored more AM spore occurrence.

2.4 EFFECT OF SOIL MICROBIAL ACTIVITIES ON AMF COMMUNITY

2.4.1 Effect of dehydrogenase activity on AMF population

The enzymatic activity of dehydrogenase indicated the total oxidative capacity of the microbial biomass (Nannipieri *et al*., 1990). Soil dehydrogenase activity can be considered as one of the good indicators of soil quality in agro systems.

Kumutha *et al*. (2006) were reported that there was 15% to 19.9% enhancement in the dehydrogenase activities over control in roots and soil of mulberry due to inoculation of *G. fasciculatum* (MGf 3).

The total dehydrogenase activity of rhizosphere soil of *Coleus forskohlii* was 2- 4 fold higher in AMF+PGPR treated plots than control. AM inoculation exhibited more activity than PGPR inoculation in the experiment, but combination performed well during all the stages of sampling (Priya and Kumutha, 2009).

According to Huang *et al*. (2009), extra radical mycelium of AMF enhanced dehydrogenase enzyme activity than mycorrhizal roots.

Sharma *et al*. (2011) reported that soil dehydrogenase activity in the rhizosphere soil of wheat plants was higher in AMF inoculated plants at tillering stage. Soil dehydrogenase and alkaline phosphatase activity had a negative impact on AMF spore density and infective propagules, but no effect on species diversity (Cibichakravarthy *et al.*, 2015).

From the six years of experiment on the AMF spore density in silty loam soil, Verzeaux *et al*. (2017) confirmed that AMF spore density was positively correlated with soil dehydrogenase activity ($p=0.62$).

2.4.2 Effect of soil respiration on AMF population

One of the most uncertain component in climate change models is soil respiration (Jones *et al*., 2003). Greater variations were seen while

measuring the soil respiration of ecosystem with similar abiotic properties (Raich and Tufekcioglu, 2000).

According to Smith and Read, (1997) the autotrophic portion of C cycling was affected by AM root colonization due to the increased photosynthetic rate and enhanced below ground demand.

Langley *et al*. (2005) concluded that mycorrhizal inoculation increased overall rhizosphere respiration in sunflower plants (p= 0.032). The increased respiration by mycorrhizal plants was due to enhanced nutrient absorption by mycorrhizae. There was a reduction in the soil respiration from dead plant in mycorrhizal system than non- mycorrhizal ones.

In arable fields mycorrhizal respiration was an important contributor to soil respiration. The respiration of arbuscular mycorrhizal hyphae contributed a significant amount of root derived carbon respiration (25.3%) and consequently of total assimilated carbon (4.8%). Soil respiration mean values were low during winter and increased over summer. Mycorrhizal respiration, on the other hand, presented no correlation with soil temperature (Moyano *et al.*, 2007).

Atkin *et al*. (2009) observed that, temperature dependence of root respiration was not altered by colonization of AM fungi. Higher rates of respiration exhibited by warm-grown AM plants than nonAM plants, irrespective of root mass. Chilling had a negligible effect on roots of AM-plants.

Zhang *et al*. (2016a) found that addition of water during drought seasons improved soil respiration. There was nonlinear relationship between soil respiration and precipitation change. AMF suppression enhanced soil respiration especially in wet season, due to increased heterotrophic component.

2.4.3 Effect of acid phosphatase activity and AMF population

Phosphatases are a broad group of enzymes that are capable of catalyzing hydrolysis of esters and anhydrous of phosphoric acid (Schmidt and Lawoski, 1961). These enzymes are believed to play critical roles in P cycles in soil ecosystems (Speir and Ross, 1978).

Dodd *et al*. (1987) noticed that, activities of phosphatase in the rhizosphere were higher for plants infected with *G. mosseae* and *G. geosporum,* compared to control plants. However, infection by *G. monosporum,* did not increase enzyme activity associated with the root or in the inner rhizosphere. Wheat plants infected with *G. mosseae* grew better than the control and had significantly higher activities of root surface phosphatase. Isolate of fungus was important for determining the phosphatase response.

Tarafdar and Marschner, (1994) found that acid and alkaline phosphatase activity were higher in the rhizospheric soil of plant inoculated with VAM. The hyphal length density was strongly and positively correlated with acid phosphatase activity. Acid phosphatase was released by extraradical mycelium. The positive correlation between root colonization by mycorrhiza and root phosphatase activity was also reported by Sumana (1998).

Priya and Kumutha (2009) reported that AM fungi inoculation enhanced acid phosphatase activity by 3-4 folds over control in *Coleus forskohlii*. Acid phosphatase activity was 46 µg in VAM inoculated rhizosphere soil and 29.5 µg in uninoculated rhizosphere soil. The enzyme activity increased from 90 DAP, and got maximum at 150 DAP. Increased root colonization by AMF resulted an increased activity of phosphatase enzyme.

According to Joner and Johansen (2000), excised mycelium of fungi *G. intraradices* and *G. claroideum* displayed significant phosphatase

activity, with maximum activity at pH 5.2–5.8. Internal phosphatases constituted 75% of the activity at pH 8.8. Phosphatase activity of both fungi increased exponentially with temperature.*G. claroideum* had higher phosphatase activity at 5^0C and 12^0C and lower activity at 20^0C.

Acid and alkaline phosphatase activities were significantly higher in mycorrhizal soybean root extracts than non-mycorrhizal ones (Abdel-Fattah, 2001). AMF inoculation significantly influenced phosphatase activity. Soil phosphatase activity was enhanced by 35.8- 70.1% in mycorrhiza inoculated soil than non- mycorrhizal control (Huang *et al*., 2009).

Study of Sato *et al*. (2015) showed that, *Rhizophagus clarus* released acid phosphatase through extra radical hyphae to soil, which helped in uptake of phosphorus.

2.5 EFFECT OF AMF ON BIOMETRIC CHARACTERS

2.5.1 Plant height

Prasad and Mertia (2005) reported that, significant positive correlation was found between average tree height, per cent root colonization ($r=0.906$, $p< 0.05$) and spore density ($r= 0.906$, $p<0.05$) in arid ecosystem.

Among the mycorrhizae isolated from different ginger growing areas in Kerala, *Glomus* sp. were more effective in growth and establishment of micro propagated ginger (Gopal *et al*., 2009).

Sery *et al*. (2016) observed that, through several mechanisms like improved plant growth, water stress tolerance and nematode resistance, native AMF improved cassava crop productivity. *Acaulospora colombiana* significantly increased the plant growth parameters, such as foliar surface area, plant height and biomass.

Sharma and Kayang (2017) conducted study regarding the effect of AMF inoculation in tea. The growth parameters like number of leaves, leaf

area, plant height, shoot length and root length, fresh and dry weight of root and shoot were higher in the treatment of consortium of three AMF species *Acaulospora scrobiculata*, *Glomus macrocarpum*, and *Rhizophagus intraradices* than inocula containing single or dual species. Root colonization was also higher in the plants treated with consortium (81.26%).

Hashem *et al*. (2019) reported that, mycorrhizal root colonization showed a significant positive correlation with shoot height, number of primary and secondary branches in chick pea.

2.5.2 Root biomass

Rohyadi *et al*. (2004) reported that, *Gigaspora margarita* inoculation increased both shoot and root weights of cowpea plants dramatically compared to non mycorrhizal plants and plants were colonized by *Glomus etunicatum* irrespective of pH.

Harikumar and Potty, (2012) observed the frequency of colonization in sweet potato which was ranged from 76- 100%, and was high in indigenous genetic stocks compared to exotic ones. Even at a lower frequency of AMF colonization, growth characters such as storage root yield and storage root dry matter percentage were enhanced, which indicated the benefit of AM association in sweet potato crop.

Kavitha and Nelson, (2014) conducted a study on the effect of AMF on the growth and yield of sunflower and found that fresh and dry weight of roots of AM inoculated plants increased. The plants inoculated with *Glomus mosseae* showed highest response followed by *Glomus fasciculatum* and *Acaulospora scrobiculata.*

2.5.3 Dry weight of plant

The study conducted by Mustafa e*t al*. (2010) showed that, the dry weight of mycorrhizal plants were higher than non- mycorrhizal plants. There was an increase in shoot dry matter content by 7.1- 27.5%, and root

dry matter content by 9.7-75.8% in *Glomus mosseae* inoculated plants over non inoculated ones. Plant height also significantly increased in inoculated plants.

According to Eulenstein *et al*. (2017) mycorrhizae inoculated plants were more efficient in terms of drymatter production and water use, than the non-mycorrhizal plants.

2.6 EFFECT OF AMF ON YIELD

Gai *et al*. (2006) reported that, *Glomus* sp. were effective on improving plant biomass and tuber yield in sweet potato as compared to other genera such as *Acaulospora* and *Scutellospora*. Among the treatments, *Glomus etunicatum* together with *G. mosseae* performed well.

Studies of Tchabi *et al*. (2009) showed that, *Dioscorea* spp. had a high percent root colonization (70- 95%) by wide range of AMF species. Spores of *Glomus etunicatum* and *Acaulospora scrobiculata* were the predominant species detected in yam fields, and these AMF species sporulated rapidly and profusely in the trap cultures with yam also. The tuber weight of *D. cayenensis*, inoculated with AMF was 20% more heavier than tuber weight of non – inoculated control.

Sharma *et al*. (2011) noticed that, AMF inoculation in unfertilized wheat plots under both elevated and flat system produced significantly higher grain yield when compared to uninoculated plots.

Lone *et al*. (2015) studied the effect of AMF inoculation on growth and development of potato. The fresh weight and dry weight of potato tubers and chlorophyll content of plants were higher in AMF inoculated plants than control. AMF had a beneficial effect on overall development and production of potato.

2.7 EFFECT OF AMF ON PHOSPHORUS UPTAKE

Mustafa *et al*. (2010) observed that, P content in the tissue of sweet

corn enhanced significantly by the application of *Glomus mossae*.

Chen *et al*. (2017) reported that, inoculation of *Glomus mossae* enhanced root and shoot biomass and also uptake of P and K. The concentration of P in the shoot and root increased by 62.5% and138.9% respectively. But, the inoculation decreased the total and available P content in the rhizospheric soil.

Panneerselvam (2017) conducted an experiment on AMF. The growth and nutrient uptake in *Coleus aromaticus* by using two mycorrizal spp. *Glomus fasciculatum* and *Glomus maragarita* were studied. Mycorrhiza plants, especially *Glomus fasciculatum* treated plants showed increased shoot and root dry weight, plant height and phosphorus content compared to other treatments. P content of plant treated with *G. fasciculatum* was 3.852 ppm, while in control it was 2.035 ppm.

Hashem *et al*. (2019) found that, inoculation of AMF enhanced the uptake of N and P in chick pea plants by 12.95% and 21.90% respectively compared to control plants.

2.8 EFFECT OF AMF ON NEMATODES POPULATION

One of major problem while farming coleus crop is nematode infection. Infestation by root knot nematode (*Meliodogyne incognita*) has reported from Kerala (Sathyrajan *et al*., 1966) and Orissa (Patnaik and Das, 1986) in Coleus. Nematode infection caused stunted growth, wilting and heavy gall formation, resulted the tubers unsuitable for marketing and consumption.

Sreekumar (2000) reported that establishment of nematode was hindered by the inoculation of *G. microcarpum*. The nematode population of all stages of life cycle was reduced significantly. During the growth and establishment of *G. microcarpum*, it passed through initial lag phase followed by logorithemic growth phase in 15 to 25 DAI. On comparison with number of nematode in the rhizosphere of mycorrhzal Chinese potato, it

was observed that suppression of nematode started from the growth of AM fungi.

Sankaranarayanan and Sundarababu (2010) conducted a study about the control of nematode population with the application of AMF. They found that, there was a reduction in nematode population (49.1%) and gall index (44%) over nematode alone treatment, when AMF was mixed with soil. Soil population of *M. incognita* suppressed by 14–49% under pot culture and 35–46% over nematode alone treatments, by the application of *G. mosseae* to black gram plants.

G.mossae was most effectively performed in the nematode pathogen suppression trials of AM group and *Acaulosporaceae* was poorly performed AM 'group' (Veresoglou and Rillig, 2011). *G. mossae* act as a potential bio-control agent of *M. incognita* in improved cowpea varieties (Odeyemi *et al*., 2010). Flor-Peregrín *et al*. (2014) reported that, *Funneliformis mosseae* reduced disease severity by 15% and final nematode densities by 45% compared to non-mycorrhizal plants.

Tchabi *et al*., (2016) found that, yam plants inoculated with combined AMF species and *Meloidogyne* sp. showed significantly lower tuber galling at harvest, than on plants having only *Meloidogyne* sp. Sery *et al*. (2016) noticed that, presence of *Acaulospora colombiana* and *A. appendicular* as single or dual inoculant significantly reduced nematode egg and population densities in cassava.

Materials and Methods

3. MATERIALS AND METHODS

The research project entitled "Soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi" was conducted in the Department of Agricultural Microbiology and Agronomy farm, College of Horticulture Vellanikkara during 2017-2019.

The materials used and methods followed during the experiment are described in this chapter.

3.1 DETAILS OF FIELD EXPERIMENT

3.1.1 Experimental location

The field experiment was conducted in the Agronomy farm, College of Horticulture, Vellanikkara, Thrissur, Kerala. Geographically the field is located at $13^0$32'N latitude and $76^0$26'E longitude, at an altitude of 40 m above mean sea level. The soil was acidic with sandy clay loam texture. The initial nutrient status of the experimental soil are presented in the Table 1.

Table 1: Initial soil nutrient status of experimental site

Sl. No.	Parameters	Values
1	pH	4.6
2	EC (dS m^{-1})	0.03
3	Organic carbon (%)	1.46 (Medium)
4	Available N (kg ha^{-1})	213 (Low)
5	Available P (kg ha^{-1})	34.29 (High)
6	Available K (kg ha^{-1})	181.33 (Medium)

3.1.2 Meteorological conditions

The data on weather variables such as rainfall, maximum and minimum temperature, relative humidity and sunshine hours were recorded at Meteorological observatory, College of Horticulture, Vellanikkara during the cropping period (June to November) and presented in Appendix I.

3.1.3 Seasons

The crop was planted on 14th June 2018 and harvested on 15th November 2018.

3.1.4 AMF mother inoculum

Five different AMF *viz.*, *Glomus fasciculatum, Glomus mosseae, Glomus etunicatum, Acaulospora* sp. and *Gigaspora* sp. were obtained from the repository maintained at Department of Agricultural Microbiology, College of Agriculture, Vellayani, KAU.

3.1.5 Planting material

The *Solenostemon rotundifolius* variety, "Nidhi" released by RARS Pattambi was used for the experiment. The variety was of five months duration, with characteristic aroma, produce large and oblong shaped tubers of good cooking quality. The seed materials were collected from Department of Agronomy, College of Horticulture, Vellanikkara.

3.1.6 Design and layout

The experiment was conducted in a randomized block design (RBD) with nine treatments and three replications. Beds of 3 m x 1.5 m size were prepared and each bed was separated by 0.5m width bunds. The plots were randomized as per the standard protocol. The layout of the experimental site is given in Fig 1.

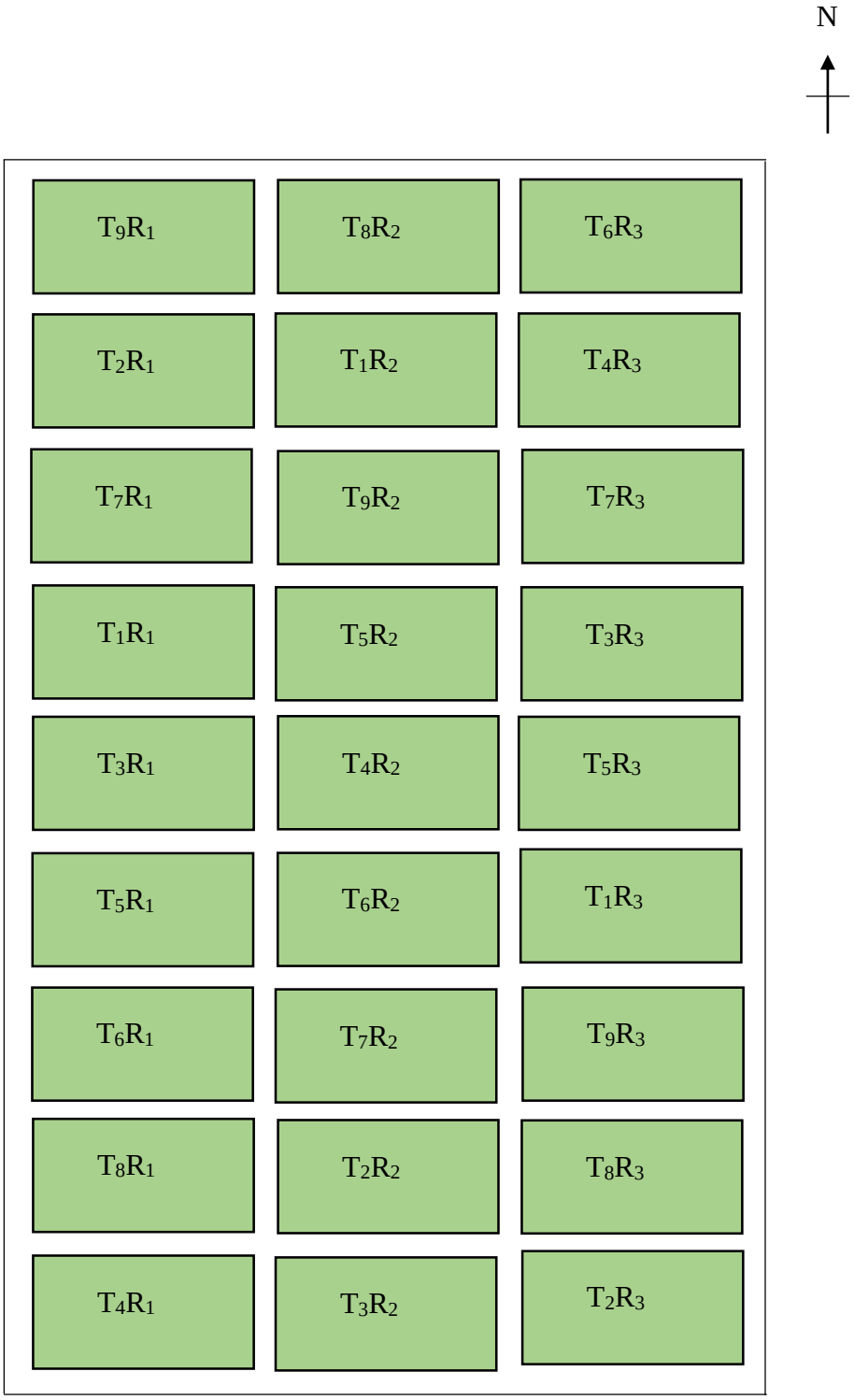


Fig 1: Layout of the experimental field

Plate 1. General view of experimental field

3.1.7 Details of the treatments

T_1: *Rhizophagus fasciculatus* (=*Glomus fasciculatum*)

T_2: *Funneliformis mosseae* (=*Glomus mosseae*)

T_3: *Glomus etunicatum*

T_4: *Acaulospora* sp.

T_5: *Gigaspora* sp.

T_6: $T_1 + T_2 + T_3 + T_4 + T_5$

T_7: Package of Practices Recommendation of KAU (2016) (Appendix II)

T_8: Organic Package (Ad hoc) of Practices Recommendation of KAU (2017) (Appendix III)

T_9: Absolute control

Farm yard manure was applied at the time bed preparation @ 10 tons ha^{-1} in all the treatments except absolute control. The cultivation practice explained in POP Recommendation of KAU (2016) was followed for mycorrhiza inoculated treatments (T_1 to T_6) and in T_7. However, Organic Package (Ad hoc) of Practices Recommendation of KAU (2017) were followed in T_8

3.2 DETAILS OF CULTIVATION

3.2.1 Raising of nursery

Raised beds were made in a small area near to experimental site after tillage and removal of stubbles. Farm yard manure @ 1 kg m^{-2} was mixed thoroughly with the soil. Uniform sized coleus tubers were planted at 30 x 15 cm spacing during the first week of May (2018). Healthy and vigorous cuttings of size of 10-15 cm from the top portion were taken for planting on 14th June, 2018.

3.2.2 Preparation of main field

Field was ploughed, stubbles were removed, clods were crushed and field was laid out in to different plots of 3m x1.5 m size, as raised bed of 15 cm height. Beds were levelled. FYM and fertilizers were added as per the treatment and mixed well with the soil.

3.2.3 Fertilizer application

Fertilizers were applied to first seven treatments as per the Package of Practices Recommendation of KAU (2016). Nitrogen, phosphorus and potassium were applied in the form of urea, rajphos and muriate of potash respectively @ 30:60:50 kg ha^{-1} as a basal dose. After 45 days of planting, top-dressed with N and K_2O @ 30 kg ha^{-1} and 50 kg ha^{-1} respectively.

3.2.4 AMF application

Ten gram per plant of different AMF mother cultures were applied to the pits at the time of planting.

3.2.5 Planting

Forty- five days old Chinese potato plant cuttings were taken from the nursery and planted in 30 cm x 15 cm spacing on raised beds.

3.2.6 After cultivation

At 45 DAP, hand weeding and earthing up was done for all the treatments and a portion of vine was covered with soil to promote tuber development. First seven treatments were top dressed with urea and muriate of potash fertilizers @ 30 kg $ha^{-1}$and 50 kg ha^{-1} respectively. PGPR mix-1 with FYM were applied in T_8 (Organic POP of KAU, 2017) at 45 DAP.

3.2.7 Harvesting

Tubers were harvested at five months after planting. Harvesting was done by digging out the tubers carefully from the soil and separated it from shoot of the plant. Observational plants and border rows were harvested separately.

3.3 OBSERVATIONS

3.3.1 Soil analysis

3.3.1.1 Soil temperature

Soil temperature was determined at a depth of 15 cm at 7.30 AM and 2.30 PM on daily basis with soil thermometer. Mean of daily soil temperature was expressed as mean monthly soil temperature.

3.3.1.2 Soil moisture

Soil moisture was determined by gravimetric method at monthly interval. Fresh weight of the soil was recorded immediately after sampling. Soil sample was oven dried at 105^0 C for 24- 48h and recorded the weight.

3.3.1.3 Soil reaction (pH)

Soil pH were determined at monthly basis, by using pH meter with glass electrode, in 1:2.5 (soil: water) suspension (Jackson, 1973).

3.3.1.4 Electrical conductivity of soil

Electrical conductivity of the soil determined by using conductivity bridge and expressed in terms of dS m^{-1} (Jackson, 1973).

3.3.1.5 Organic carbon (%)

Initial and final organic carbon content of the experimental soil were determined by Wakley and Black method (1934).

3.3.1.6 Available nitrogen in soil

Available nitrogen content in the soil was determined before and after the experiment, by alkaline permanganate method (Subbiah and Asija, 1956) and expressed as kg ha^{-1}.

3.3.1.7 Available phosphorus in soil

Ascorbic acid reduced molybdo phosphoric blue color method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965) was followed to determine available phosphorus content in the soil collected before and after the experiment.

3.3.1.8 Available potassium in soil

Initial and final content of available potassium in the soil extracted by neutral normal ammonium acetate and estimated by flame photometry (Jackson, 1973).

3.3.2 Arbuscular mycorrhizal fungi

3.3.2.1 Per cent root colonization

Per cent root colonization of AMF in Chinese potato roots was assessed by the procedure as described by Philips and Hayman (1970). The root colonization per cent was determined by following equation.

$$\text{Per cent root colonization} = \frac{\text{Number of root segments colonized}}{\text{Total number of root segments examined}} \text{ X } 100$$

3.3.2.2 Isolation of AMF spores from soil

Spores of AMF in soil were determined by wet sieving and decantation method as described by Gerdemann and Nicolson (1963).

The soil suspension was passed through a series of sieves (2mm, 500 µm, 250µm, 105µm, 75µm, 45µm, 37µm) arranged in the descending order of their mesh size. The supernatant from each beaker was separately filtered

through Whatman No.1 filter paper and the contents were examined for spores under stereo zoom microscope (40x).

3.3.2.3 Morphological characterization of AMF spore

Spores with similar morphological characters were picked by needle and population of each morphotypes were enumerated. Slides of morphologically different spores were prepared by using lactic acid: glycerol: water (1: 1: 1). Different morphological characters of the spore such as spore color, shape, size, number of spore wall and hyphal characters were recorded from each treatments at monthly interval.

3.3.2.4 Diversity study of AMF spore

Diversity of AMF spores in the soil were determined using Shannon-Wiener index (Shannon and Weaver, 1949). It is a commonly used mathematical measure to study species diversity in a community. Shannon's index tells about the abundance and evenness of the species, and higher the value of the index indicate higher diversity.

Shannon's index estimated by the formula:

$$H' = \sum_{i=1}^{S} pi \ln pi$$

Where,

H'= Shannon diversity index

p_i = (ni/N)

ni = Number of individuals of i^{th} species

N = Total number of individuals in the sample

3.3.3 Soil microbial parameters

3.3.3.1 Dehydrogenase enzyme activity

Dehydrogenase activity in the soil samples was determined by following the procedure as described by Casida *et al*. (1964), at monthly interval.

Concentration of formazan formed in the soil samples were determined by using standard curve, prepared using graded concentration of formazan. The results were expressed as µg of triphenyl formazan (TPF) formed g^{-1} soil per day.

3.3.3.2 Soil respiration (Carbon dioxide evolution)

Soil respiration or carbon dioxide evolution of different soil samples were determined by alkali trap method (Chhonkar *et al*., 2007), at monthly interval. The CO_2 evolved was determined by the following equation.

mg CO_2/g soil= (Blank value- Titre value) x (Normality of acid x 22)

3.3.3.3 Acid phosphatase enzyme activity

Soil phosphatase activity was determined as per the procedure described by Tabatabai and Bremner (1969), at monthly interval.

The phosphatase activity in the soil samples were expressed as µg para nitrophenol g^{-1} h^{-1} using the standard curve prepared by different concentrations of p- nitrophenol phosphate.

3.3.4 Biometric characters of plant

Biometric observation of the plants were taken at monthly interval, for five randomly selected and tagged representative plants per bed. A row of plants in each plot were used for destructive sampling.

3.3.4.1 Height of the plant

The height of the plants were measured from base of the plant to growing tip and expressed in cm at monthly interval.

3.3.4.2 Root biomass of the plant

Fresh weight of the Chinese potato roots were taken and expressed in gram at monthly interval.

3.3.4.3 Dry weight of the plant

Weight of the whole plant was determined after shade dry followed by oven dry (70^0C), till no fluctuation in the value.

3.3.4.4 Number of days taken for first flowering

Days taken for first flowering were recorded for each plots as and when the flowers were noticed on daily basis.

3.4 TUBER YIELD

Fresh weight of the tubers from each plots was taken immediately after the harvest at five months after planting.

3.4.1 Tuber yield per hectare

Mean of the tuber yield from each treatment was worked out and expressed in tons per hectare.

3.4.2 Weight of the tubers per plant

Tuber weight of the observational plants were recorded and average was worked out.

3.5 P UPTAKE BY PLANT

Plant samples were shade dried and then oven dried at 70± 5^0C till constant weight were obtained. Samples were powdered to pass through 0.5

mm mesh. Phosphorus content in plant was determined calorimetrically by vanado- molybdo- phosphoric (Bartons reagent) yellow color method (Jackson, 1973). Total P uptake was calculated by multiplying P content in plant sample with total dry weight of plants and expressed as kg ha^{-1}.

3.5 ENUMERATION OF NEMATODE POPULATION FROM SOIL

Soil sample of 250 g was taken from rhizospheric region of Chinese potato analyzed for nematode population. Nematodes were extracted from different treatments by Cobb's sieving and decanting technique (Cobb, 1918). The residues were collected from 100, 200 and 325 mesh sieves in a 100 ml beaker. The collected residues were cleared by using the procedure of modified Baermann funnel technique (Schindler, 1961). Nematode suspension was collected in the beaker after 12 h and the volume was made up to 100 ml by adding water. A counting dish was taken and one ml of aliquot was pipetted on it. The number of nematodes were counted under a stereoscopic microscope. Total number of nematodes in 250 g soil was determined by multiplying mean population (based on five such count) by hundred. Number of plant parasitic nematodes and saprophytic nematodes were separately taken based upon the morphological characters and mobility (Carneiro *et al*., 2017).

3.6 STATISTICAL ANALYSIS

Analysis of variance was performed by statistical software package WASP 2.0. Correlation study among different variables were also determined by Pearson correlation coefficient by using OPSTAT.

Results

3. RESULT

The research work was carried out with an aim to study the effect of soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi (AMF) and also to evaluate effect of AMF on the growth and yield of Chinese potato plants. The results obtained during the study are presented in this chapter.

4.1 TOTAL SPORENUMBER OF AMF IN MOTHER INOCULUM

Five AMF mother inoculum *viz*, *Rhizophagus fasciculatus*, *Funneliformis mosseae*, *Glomus etunicatum*, *Acaulospora* sp., and *Gigaspora* sp. were obtained from Department of Agricultural Microbiology, College of Agriculture, Vellayani. Total spore count were enumerated in each mother inoculum (Table 2).

Highest spore count were recorded in the case of *Rhizophagus fasciculatus* (63 spores g^{-1} inoculum) followed by *Funneliformis mosseae* (59 spores g^{-1} inoculum), and lowest was in case of *Acaulospora* sp. (50 spore g^{-1} inoculum).

Table 2: Total spore count in mother culture of arbuscular mycorrhizal fungi

Sl. No.	AMF culture	Total spore count/ g of inoculum
1	*Rhizophagus fasciculatus*	63
2	*Funneliformis mosseae*	59
3	*Glomus etunicatum*	54
4	*Acaulospora* sp.	50
5	*Gigaspora* sp.	58

4.2 EFFECT OF DIFFERENT TREATMENTS ON ARBUSCULAR MYCORRHIZAL FUNGI

4.2.1 Root colonization by AMF in Chinese potato (*Solenostemon rotundifolius*)

The effect of different treatments on AMF root colonization in Chinese potato were statistically significant throughout the crop growth (Table 3).

The per cent root colonization in Chinese potato crop ranged from 45.0% to 93.33%. At 30 DAP, higher root colonization (80%) was recorded by T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5). Lowest root colonization was recorded in the absolute control plots (45%). AMF inoculated plants showed better root colonization than non-inoculated plots.

The T_5 (*Gigaspora* sp.) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) showed 76.67% root colonization per cent at 60 DAP, but T_7 (POP recommendations of KAU, 2016) and T_9 (Absolute control) had lower root colonization per cent (50% and 46.67% respectively). Root colonization per cent at 60 DAP was lesser than 30 DAP except in T_8 (Organic POP of KAU, 2017).

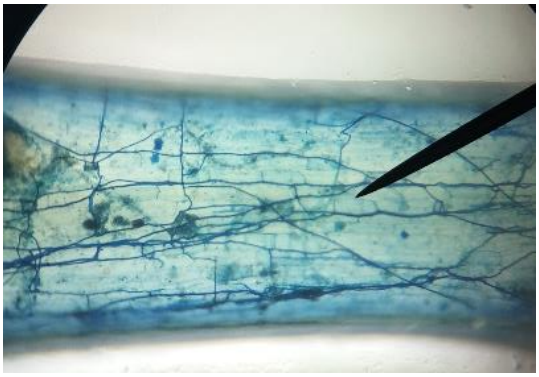
There was an increase in the root colonization per cent at 90 DAP when compared with 60 DAP. At 90 DAP, higher root colonization (90.0%) was observed in T_2 (*Funneliformis mosseae*), T_3 (*Glomus etunicatum*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) treated plants. Lowest root colonization (66.67%) was reported in T_9 (Absolute control).

Higher root colonization (93.33%) at 120 DAP was recorded T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5). Root colonization in all treatments increased after 90 days of planting, but decreased in T_3 (*Glomus etunicatum*) 86.67% at 120 DAP. Uninoculated plants showed 83.3% root colonization.

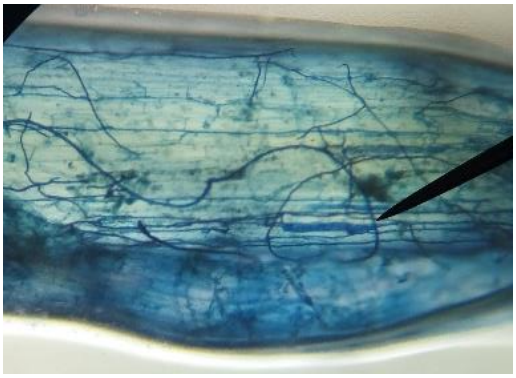
Table 3: Effect of AMF cultures on root colonization of Chinese potato at monthly interval

Treatments	Root colonization (%)			
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**
T_1(*Rhizophagus fasciculatus*)	75.00^{ab}	66.67^{ab}	80.00^{ab}	93.33^{a}
T_2 (*Funneliformis mosseae*)	80.00^{a}	73.33^{a}	90.00^{a}	93.33^{a}
T_3 (*Glomus etunicatum*)	75.00^{ab}	66.67^{ab}	90.00^{a}	86.67^{b}
T_4 (*Acaulospora* sp.)	80.00^{a}	60.00^{bc}	80.00^{ab}	93.33^{a}
T_5 (*Gigaspora* sp.)	65.00^{b}	76.67^{a}	86.67^{a}	86.67^{b}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	80.00^{a}	76.67^{a}	90.00^{a}	93.33^{a}
T_7 (POP recommendations of KAU, 2016)	50.00^{c}	50.00^{cd}	70.00^{bc}	83.33^{b}
T_8 (Organic POP of KAU, 2017)	50.00^{c}	60.00^{bc}	73.33^{bc}	83.33^{b}
T_9 (Absolute control)	45.00^{c}	46.67^{d}	66.67^{c}	83.33^{b}
CD(0.05)	11.53	10.92	13.01	6.66

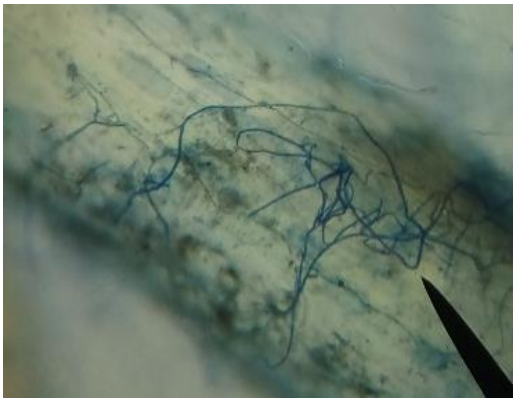
DAP – Days after planting



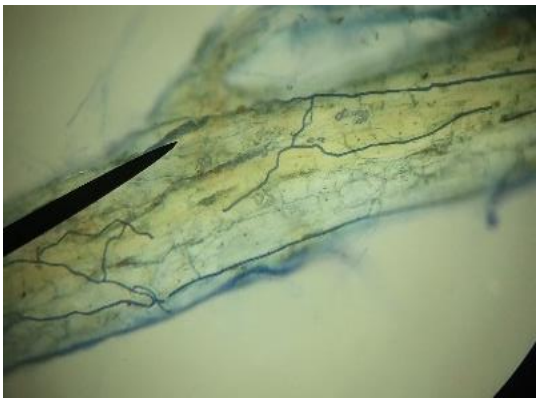
T_1 (*Rhizophagus fasciculatus*)



T_2 (*Funneliformis mosseae*)



T_4 (*Acaulospora* sp.)



T_6 (T_1 +T_2 +T_3 +T_4 +T_5)

Plate 2. AMF root colonization in Chinese potato at 120 DAP

4.2.2 Total AMF spore count

Population of AMF spores recorded on monthly basis showed significant differences among treatments (Table 4).

AMF spore count in the experimental site at the start of the experiment was 23.26 spores/ g soil. At 30 DAP, spore count of the treatment T_1 (*Rhizophagus fasciculatus*) was highest (41.13 spores/ g soil) followed by T_5 (*Gigaspora* sp.) with 38.00 spores/ g soil.

There was a reduction in AMF spore abundance at 60 DAP as compared to 30 DAP, except in T_8 (Organic POP of KAU, 2017). Treatment T_6 (T_1 +T_2 +T_3 +T_4 +T_5) recorded highest spore count (29.11 spores/ g soil) at 60 DAP. Lowest (13.48 spores/ g soil) was in case of T_7 (POP recommendations of KAU, 2016).

Highest total spore count at 90 DAP was observed in T_1 (*Rhizophagus fasciculatus*) treated plots (32.96 spores/ g soil), followed by T_3 (*Glomus etunicatum*), T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and T_2 (*Funneliformis mosseae*) treated plots. Lowest (14.55 spores/ g soil) was recorded in T_9 (Control plots).

Number of AMF spores at 120 DAP were higher than previous month, except in T_8 (Organic POP of KAU, 2017). The experimental plot treated with T_6 (T_1 +T_2 +T_3 +T_4 +T_5) had highest (41.06 spores/ g soil) and T_8 (Organic POP of KAU, 2017) had lowest spore population (15.27 spores/ g soil) at 120 DAP.

At 150 DAP, highest spore count (38.44 spores/ g soil) was observed in T_4 (*Acaulospora* sp.) treated plot followed by T_2 (*Funneliformis mosseae*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5). Total spore count was lowest (19.47 spores/ g soil) in T9 (Absolute control plots).

As a whole, spore count of AMF inoculated plots were higher than un-inoculated plots.

Table 4: Effect of different treatments on total AMF spore count at monthly interval

Treatments	AMF spore count (1 g soil)				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	41.13^{a}	21.61^{c}	32.96^{a}	36.88^{b}	24.17^{d}
T_2 (*Funneliformis mosseae*)	36.70^{bc}	14.53^{de}	29.31^{ab}	29.35^{d}	35.08^{ab}
T_3 (*Glomus etunicatum*)	36.19^{bc}	15.17^{de}	31.50^{ab}	32.52^{c}	29.55^{c}
T_4 (*Acaulospora* sp.)	36.13^{bc}	21.73^{c}	22.94^{cd}	37.04^{b}	38.44^{a}
T_5 (*Gigaspora* sp.)	38.00^{b}	24.76^{b}	26.92^{bc}	33.30^{c}	31.85^{bc}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	34.00^{c}	29.11^{a}	30.49^{ab}	41.06^{a}	33.69^{abc}
T_7 (POP recommendations of KAU, 2016)	22.94^{d}	13.48^{e}	19.29^{de}	25.95^{e}	31.97^{bc}
T_8 (Organic POP of KAU, 2017)	15.85^{f}	16.16^{d}	15.34^{e}	15.27^{f}	20.13^{d}
T_9 (Absolute control)	19.50^{e}	14.24^{de}	14.55^{e}	16.26^{f}	19.47^{d}
CD(0.05)	3.00	1.92	5.42	1.65	4.82

DAP – Days after planting Initial AMF spore count (1 g soil) = 23.26

4.2.3 Morphological characters of AMF spores

Morphological characters of AMF spores such as color, shape, size, number of spore wall and hyphae were recorded at monthly interval for different treatments (Table 5- 9). Number of morphotypes recorded from different treatments at monthly interval are presented in Table 10.

At 30 DAP, highest number of morphotypes (14) were noted T_6 (T_1 +T_2 +T_3 +T_4 +T_5) followed by T_2 (*Funneliformis mosseae*) with 13 and T_1 (*Rhizophagus fasciculatus*) with 12. Lowest number of mophotypes (7) were recorded in absolute control and T_3 (*Glomus etunicatum*).

Number of morphotypes recorded at 60 DAP was lesser than 30 DAP. Highest number of morphotypes (5) were recorded in T_5 (*Gigaspora* sp.) and lowest (3) were in T_1 (*Rhizophagus fasciculatus*), T_4 (*Acaulospora* sp.), T_7 (POP recommendations of KAU, 2016) and T_8 (Organic POP of KAU, 2017).

At 90 DAP, highest number of morphotypes (5) were recorded in T_1 (*Rhizophagus fasciculatus*) and T_7 (POP recommendations of KAU, 2016). Lowest number of morphotypes (3) were recorded in T_8 (Organic POP of KAU, 2017).

Number of morphotypes recorded at 120 DAP was higher than 90 DAP and ranged from 6 to 10. Highest number of morphotypes (10) were recorded from T_2 (*Funneliformis mosseae*) and lowest (6) was from T_1 (*Rhizophagus fasciculatus*), T_4 (*Acaulospora* sp.) and T_9 (Absolute control).

At 120 DAP highest number of morphotypes (9) were recorded from T_2 (*Funneliformis mosseae*) followed by T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and lowest (4) from T_9 (Absolute control).

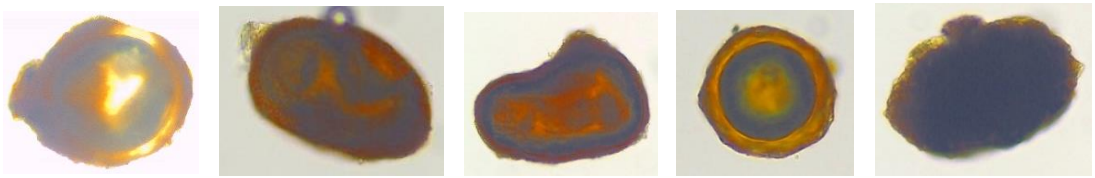
Table 5: Morphological characters of AMF spores in the rhizosphere soil of Chinese potato at 30 DAP (July, 2018)

Treatment	Morphological characters of AMF spores						
	Code for morphotypes	Color	Shape	Size (µm)	Spore wall No.	Hyphae	
						No.	Characters
T_1 (*Rhizophagus fasciculatus*)	AMF A 1.1	Yellow	Sub globose	126	2	1	Straight
	AMF A 1.2	Brown	Ellipsoid	75.7	2	1	Bulbous
	AMF A 1.3	Brown	Elongated	80.6	1	Absent	-
	AMF A 1.4	Yellow	Globose	29.3	2	1	Bulbous
	AMF A 1.5	Black	Ellipsoid	59.3	1	1	Bulbous
	AMF A 1.6	Black	Globose	31.5	1	Absent	-
	AMF A 1.7	Yellow	Ellipsoid	66.3	2	2	Curled
	AMF A 1.8	Brown	Globose	63.3	2	Absent	-
	AMF A 1.9	Yellow	Ellipsoid	63.8	3	1	Straight
	AMF A 1.10	Black	Globose	62.2	1	Absent	-
	AMF A 1.11	Yellow	Globose	59.3	2	Absent	-
	AMF A 1.12	Yellow	Sub globose	111	2	1	Bulbous
T_2 (*Funneliformis mosseae*)	AMF A 2.1	Black	Globose	37.5	1	1	Straight
	AMF A 2.2	Yellow	Sub globose	54.2	2	1	Bulbous
	AMF A 2.3	Yellow	Irregular	43.1	2	1	Curled
	AMF A 2.4	Black	Irregular	40.2	2	Absent	-
	AMF A 2.5	Pale yellow	Globose	39.6	2	Absent	-
	AMF A 2.6	Dark yellow	Globose	28.2	3	Absent	-
	AMF A 2.7	Dark brown	Sub globose	83.8	1	>1	Straight
	AMF A 2.8	Yellow	Sub globose	50.7	2	Absent	-
	AMF A 2.9	Dark brown	Sub globose	42.2	1	>1	Straight
	AMF A 2.10	Light yellow	Globose	50.0	2	Absent	-
	AMF A 2.11	Yellow	Sub globose	50.1	2	2	Straight
	AMF A 2.12	Brown	Sub globose	68.3	2	1	Straight

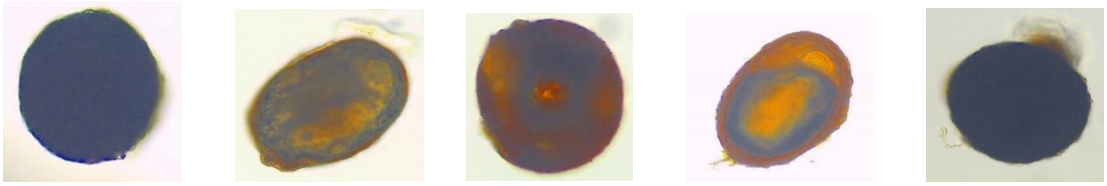
	AMF A 2. 13	Yellow	Oval	75.8	2	1	Straight
T_3 (*Glomus etunicatum*)	AMF A 3.1	Dark brown	Globose	57.7	2	1	Straight
	AMF A 3.2	Yellow	Globose	120	1	>1	Straight
	AMF A 3.3	Dark brown	Globose	102	2	1	Straight
	AMF A 3.4	Yellow	Sub globose	71.9	2	1	Straight
	AMF A 3.5	Brown	Oval	70.5	3	>1	Straight
	AMF A 3.6	yellow	Globose	49.5	-	1	Straight
	AMF A 3.7	Yellow	Sub globose	156	2	Absent	-
T_4 (*Acaulospora* sp.)	AMF A 4.1	Dark brown	Globose	80.5	2	2	Straight
	AMF A 4.2	Brown	Globose	48.5	2	1	Straight
	AMF A 4.3	Dark brown	Oval	108	2	2	Bulbous
	AMF A 4.4	Brown	Oval	65.8	2	1	Bulbous
	AMF A 4.5	Yellow	Oval	65.6	2	2	Straight,
	AMF A 4.6	Black	Globose	51.0	-	1	-
	AMF A 4.7	Dark yellow	Irregular	59.2	-	1	Straight
	AMF A 4.8	Yellow	Globose	54.7	3	>1	Straight
	AMF A 4.9	Dark brown	Globose	95.0	1	>1	Curled
	AMF A 4.10	Golden	Ellipsoid	76.7	1	1	Curled
	AMF A 4.11	Golden	Globose	0.4	1	>1	Straight
	AMF A 4.12	Brown	Oval	51.4	2	3	Curled
T_5 (*Gigaspora* sp.)	AMF A 5.1	Black	Globose	68.2	1	Absent	-
	AMF A 5.2	Black	Sub globose	111	1	1	Straight
	AMF A 5.3	Brown	Sub globose	86.8	2	1	Bulbous
	AMF A 5.4	Brown	Sub globose	183	2	Absent	-
	AMF A 5.5	Light	Globose	39.6	2	>1	Curled
	AMF A 5.6	Dark brown	Sub globose	46.1	2	2	Straight
	AMF A 5.7	Brown	Ellipsoid	74.5	2	1	Straight
	AMF A 5.8	Yellow	Ellipsoid	60.2	3	1	Bulbous
	AMF A 5.9	Light yellow	Globose	45.6	2	3	Straight
	AMF A 5.10	Dark brown	Globose	45.4	2	3	Straight
	AMF A 5.11	Dark brown	Globose	51.4	2	2	Straight
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	AMF A 6.1	Dark yellow	Globose	47.5	2	4	Curled
	AMF A 6.2	Black	Globose	52.7	1	2	Straight
	AMF A 6.3	Black	Globose	57.5	1	1	Straight

	AMF A 6.4	Black	Sub globose	60.0	2	1	Straight
	AMF A 6.5	Pale yellow	Globose	50.9	2	>1	Straight
	AMF A 6.6	Black	Sub globose	47.5	2	>1	Straight
	AMF A 6.7	Brown	Oval	64.1	2	1	Straight
	AMF A 6.8	Dark brown	Sub globose	67.3	2	>1	Straight
	AMF A 6.9	Black	Sub globose	137	1	Absent	-
	AMF A 6.10	Black	Globose	74.0	2	Absent	-
	AMF A 6.11	Yellow	Ellipsoid	60.7	2	Absent	-
	AMF A 6.12	Pale yellow	Globose	79.1	2	Absent	-
	AMF A 6.13	Dark brown	Sub globose	68.4	2	1	Straight
	AMF A 6.14	Brown-black	Globose	136	1	>1	Straight
T_7 (POP recommendations of KAU, 2016)	AMF A 7.1	Black	Sub globose	123.0	1	>1	Straight
	AMF A 7.2	Brown	Sub globose	108	2	2	Straight
	AMF A 7.3	Dark brown	Globose	53.2	2	3	Straight
	AMF A 7.4	Dark yellow	Globose	63.1	2	Absent	-
	AMF A 7.5	Pale yellow	Oval	44.4	2	>1	Straight
	AMF A 7.6	Black	Oval	132.0	1	3	Small
	AMF A 7.7	Black	Oval	83.6	1	>1	Small
	AMF A 7.8	Pale yellow	Globose	56.8	1	1	Curled
	AMF A 7.9	Black-brown	Ellipsoid	142	2	>1	Straight
	AMF A 7.10	Dark brown	Ellipsoid	69.6	2	1	Hyphal knob
	AMF A 7.11	Yellow	Globose	51.1	2	2	Small
T_8 (Organic POP of KAU, 2017)	AMF A 8.1	Black	Globose	38.1	1	>1	Straight
	AMF A 8.2	Dark yellow	Sub globose	57.4	2	Absent	-
	AMF A 8.3	Brown	Oval	69.3	2	1	Straight
	AMF A 8.4	Pale yellow	Sub globose	43.6	2	3	Straight
	AMF A 8.5	Brown	Sub globose	49.4	2	1	Bulbous
	AMF A 8.6	Brown-black	Globose	65.1	1	1	Straight
	AMF A 8.7	Dark brown	Globose	135	-	1	Straight
	AMF A 8.8	Dark brown	Sub globose	72.2	2	Absent	-
	AMF A 8.9	Brown	Ellipsoid	66.6	2	>1	Straight
	AMF A 8.10	Pale yellow	Elongated	121	2	Absent	-

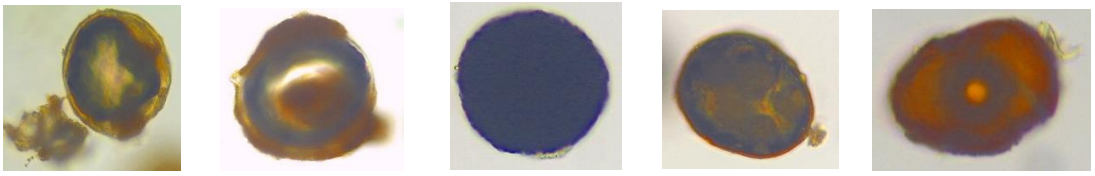
	AMF A 8.11	Golden	Globose	43.3	2	Absent	-
T_9 (Absolute control)	AMF A 9.1	Brown	Elongated	67.4	3	>1	Bulbous
	AMF A 9.2	Black	Sub globose	80.4	1	>1	Straight
	AMF A 9.3	Golden	Sub globose	51.8	2	3	Straight
	AMF A 9.4	Pale yellow	Ellipsoid	42.7	1	Absent	-
	AMF A 9.5	Yellow	Globose	45.3	2	Absent	-
	AMF A 9.6	Black	Globose	52.1	1	>1	Straight
	AMF A 9.7	Dark yellow	Sub globose	49.8	2	1	Straight



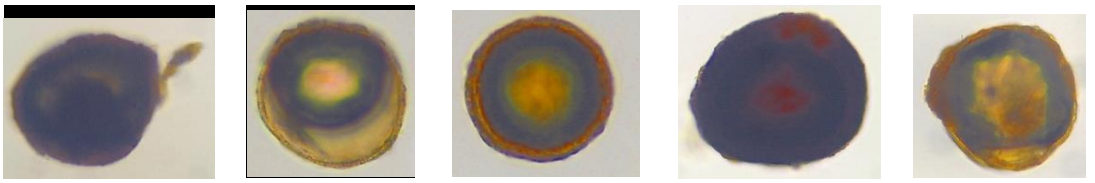
AMF A 1.1 AMF A 1.2 AMF A 1.3 AMF A 1.4 AMF A 1.5



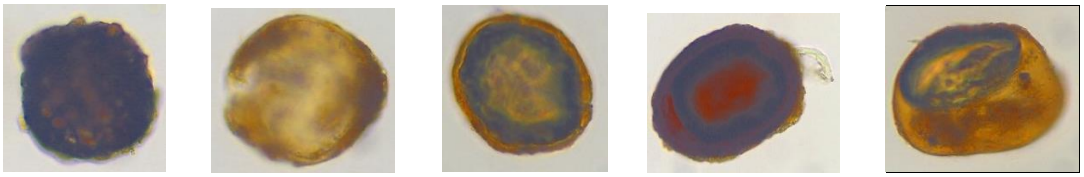
AMF A 1.6 AMF A 1.7 AMF A 1.8 AMF A 1.9 AMF A 1.10



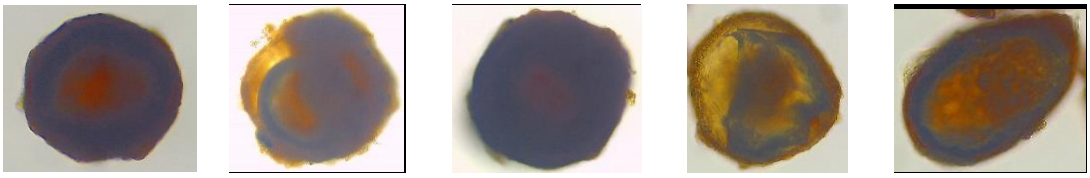
AMF A 1.11 AMF A 1.12 AMF A 2.1 AMF A 2.2 AMF A 2.3



AMF A 2.4 AMF A 2.5 AMF A 2.6 AMF A 2.7 AMF A 2.8



AMF A 2.9 AMF A 2.10 AMF A 2.11 AMF A 2.12 AMF A 2.13



AMF A 3.1 AMF A 3.2 AMF A 3.3 AMF A 3.4 AMF A 3.5

Plate 3. AMF spores isolated from different treatments at 30 DAP (July, 2018)

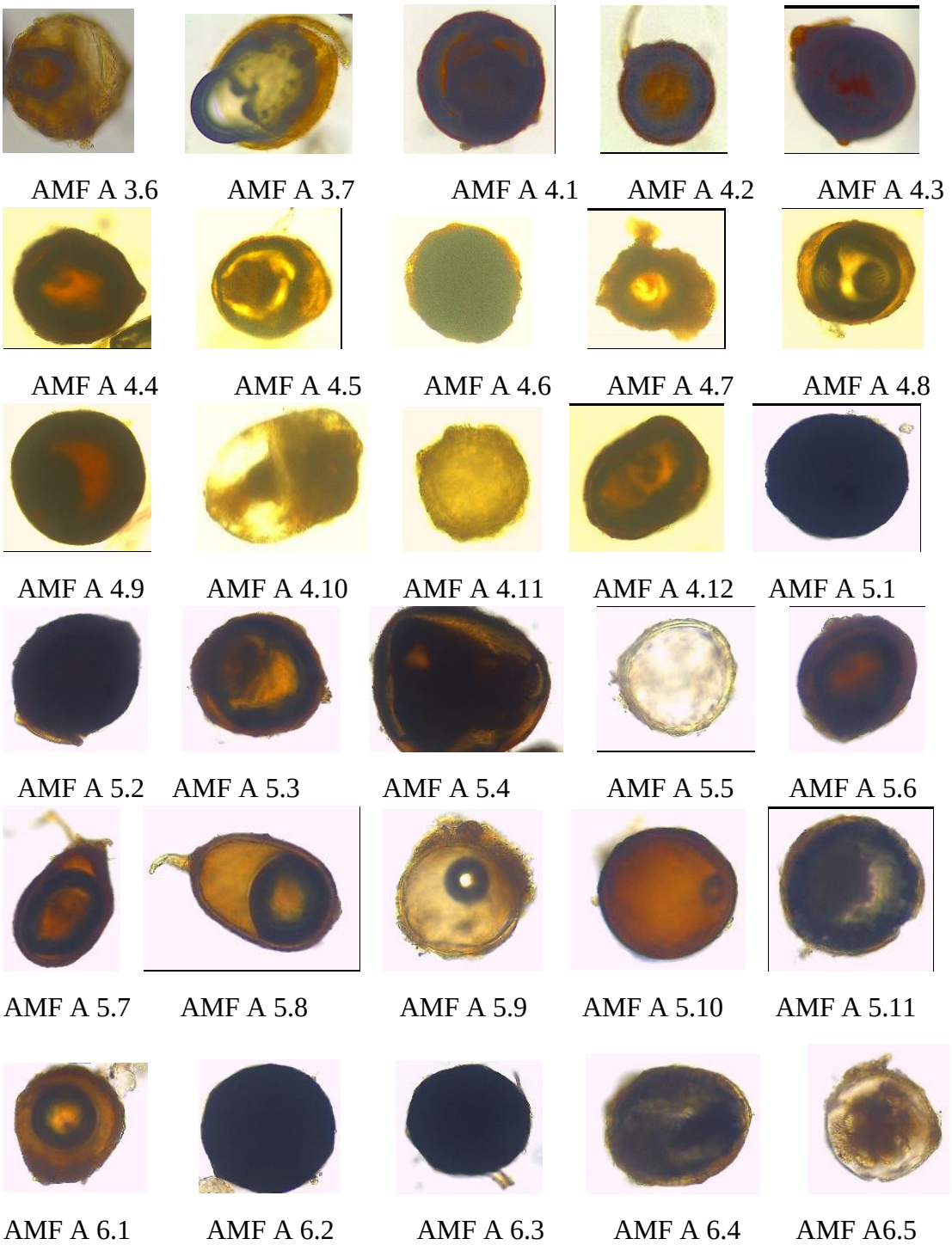
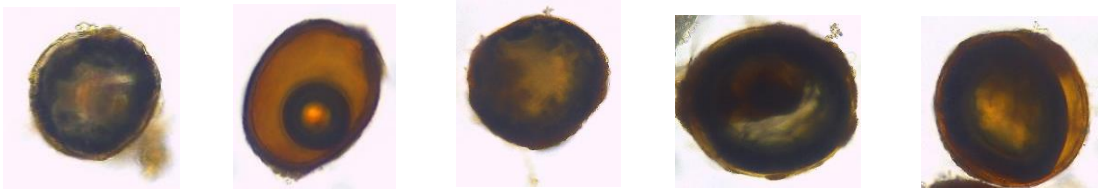
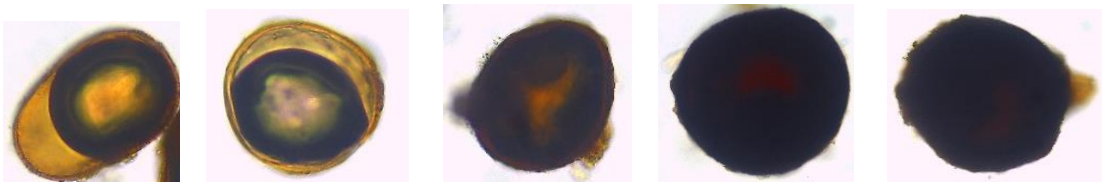


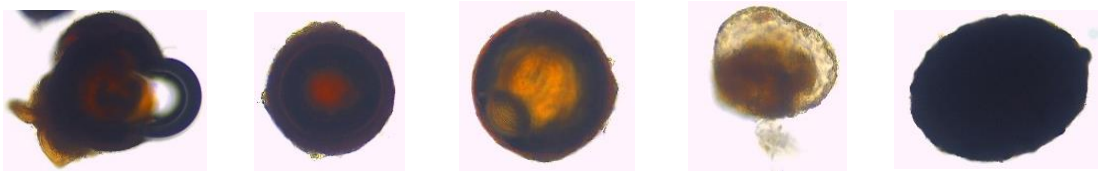
Plate 3. AMF spores isolated from different treatments at 30 DAP (July, 2018)



AMF A 6.6 AMF A 6.7 AMF A 6.8 AMF A 6.9 AMF A 6.10

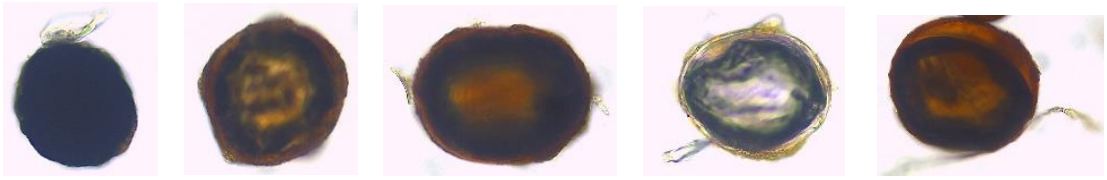


AMF A 6.11 AMF A 6.12 AMF A 6.13 AMF A 6.14 AMF A 7.1

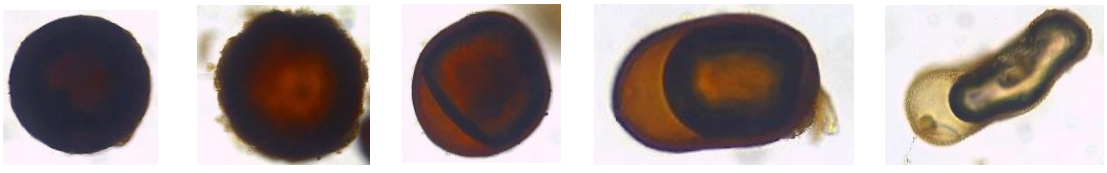


AMF A 7.2 AMF A 7.3 AMF A 7.4 AMF A 7.5 AMF A 7.6

AMF A 7.7 AMF A 7.8 AMF A 7.9 AMF A 7.10 AMF A 7.11

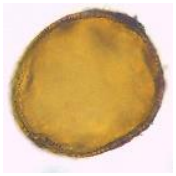


AMF A 8.1 AMF A 8.2 AMF A 8.3 AMF A 8.4 AMF A 8.5

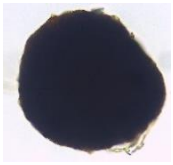


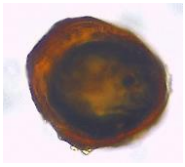
AMF A 8.6 AMF A 8.7 AMF A 8.8 AMF A 8.9 AMF A 8.10

Plate 3. AMF spores isolated from different treatments at 30 DAP (July, 2018)


AMF A 8.11


AMF A 9.1


AMF A 9.2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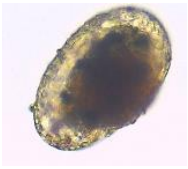
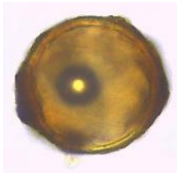

AMF A 9.4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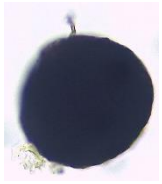
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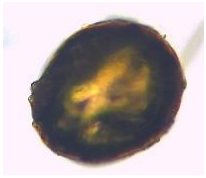

AMF A 9.7

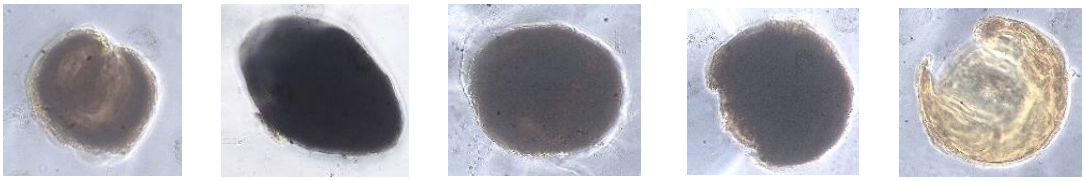
Plate 3. AMF spores isolated from different treatments at 30 DAP (July, 2018)

Table 6: Morphological characters of AMF spores in the rhizosphere soil of Chinese potato at 60 DAP (Aug, 2018)

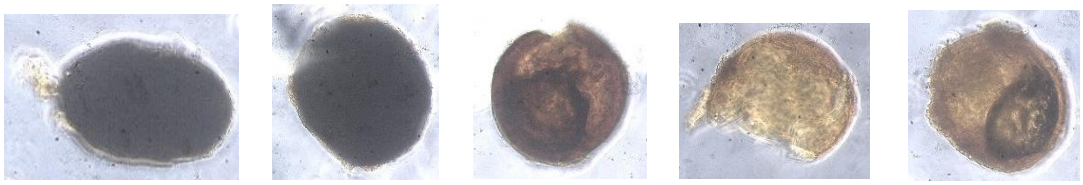
Treatment	Morphological characters of AMF spores						
	Code for morphotypes	Color	Shape	Size (µm)	Spore wall No.	Hypha	
						No.	Characters
T_1 (*Rhizophagus fasciculatus*)	AMF B 1.1	Pale yellow	Globose	103	2	Absent	-
	AMF B 1.2	Pale yellow	Sub globose	118	2	Absent	-
	AMF B 1.3	Black	Globose	38.4	1	1	Straight
T_2 (*Funneliformis mosseae*)	AMF B 2.1	Black	Sub globose	111	1	>1	Straight
	AMF B 2.2	Yellow	Globose	84.7	3	1	Bulbous
	AMF B 2.3	Brown	Sub globose	87.4	2	2	Straight
	AMF B 2.4	Black	Oval	79.8	1	>1	Curled
T_3 (*Glomus etunicatum*)	AMF B 3.1	Black	Globose	154	1	>1	Straight
	AMF B 3.2	Dark brown	Globose	135	1	Absent	-
	AMF B 3.3	Pale yellow	Globose	114	2	1-2	Straight
	AMF B 3.4	Dark brown	Ellipsoid	126	1	>1	Straight
T_4 (*Acaulospora* sp.)	AMF B 4.1	Black	Sub globose	112	1	>1	Straight
	AMF B 4.2	Brown	Globose	93	2	Absent	-
	AMF B 4.3	Pale yellow	Globose	110	2	1	Straight
T_5 (*Gigaspora* sp.)	AMF B 5.1	Yellow	Sub globose	105	2	>1	Curved
	AMF B 5.2	Yellow	Sub globose	87.2	-	>1	Curled
	AMF B 5.3	Black	Sub globose	89	1	>1	Straight
	AMF B 5.4	Dark brown	Oval	97.9	2	1	Bulbous
	AMF B 5.5	Pale yellow	Globose	154	2	>1	Straight
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	AMF B 6.1	Yellow	Sub globose	73.2	-	>1	Straight
	AMF B 6.2	Yellow	Ellipsoid	68.2	2	Absent	-
	AMF 6.3	Brown	Globose	96.5	2	>1	Straight
	AMF 6.4	Black	Globose	98.5	1	>1	Straight
	AMF B 7.1	Brown	Sub globose	110	2	>1	Straight

T_7 (POP recommendations of KAU, 2016)	AMF B 7.2	Black	Globose	104	1	>1	Straight
	AMF B 7.3	Pale yellow	Ellipsoid	98.4	2	>1	Curled
T_8 (Organic POP of KAU, 2017)	AMF B 8.1	Black	Globose	111	1	>1	Bulbous
	AMF B 8.2	Brown	Sub globose	103	2	>1	Straight
	AMFB 8.3	Yellow	Sub globose	77	2	Absent	-
T_9 (Absolute control)	AMF B 9.1	Black	Sub globose	121	1	1	Bulbous
	AMF B 9.2	Yellow	Oval	65.4	2	>1	Straight
	AMF B 9.3	Yellow	Globose	68.2	2	>1	Straight
	AMF B 9.4	Brown	Globose	75.4	2	>1	Straight

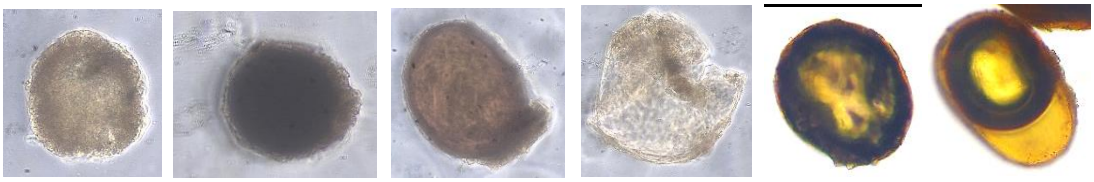
AMF B 1.1 AMF B 1.2 AMF B 1.3 AMF B 2.1 AMF B 2.2



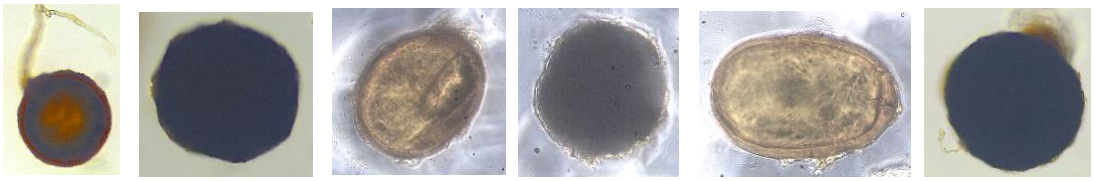
AMF B 2.3 AMF B 2.4 AMF B 3.1 AMF B 3.2 AMF B 3.3



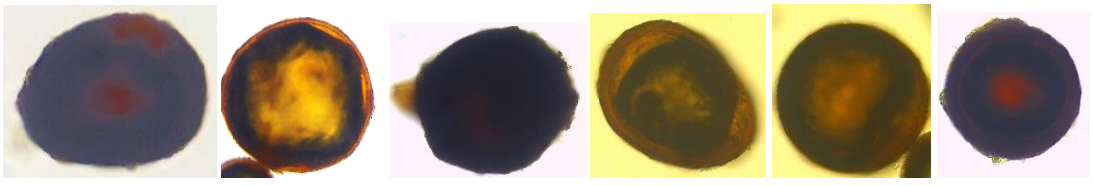
AMF B 3.4 AMF B 4.1 AMF B 4.2 AMF B 4.3 AMF B 5.1



AMF B 5.2 AMF B 5.3 AMF B 5.4 AMF B 5.5 AMF B 6.1 AMF B 6.2



AMF B 6.3 AMF B 6.4 AMF B 7.1 AMF B 7.2 AMF B 7.3 AMF B 8.1



AMF B 8.2 AMF B 8.3 AMF B 9.1 AMF B 9.2 AMF B 9.3 AMF B 9.4

Plate 4. AMF spores isolated from different treatments at 60 DAP (Aug, 2018)

Table 7: Morphological characters of AMF spores in the rhizosphere soil of Chinese potato at 90 DAP (Sept, 2018)

Treatment	Morphological characters of AMF spores						
	Code for morphotypes	Color	Shape	Size (µm)	Spore wall No.	Hypha	
						No.	Characters
T_1 (*Rhizophagus fasciculatus*)	AMF C 1.1	Brown	Globose	63.2	2	1	Curved
	AMF C 1.2	Yellow	Ellipsoid	45.7	1	1	Straight
	AMF C 1.3	Black	Ellipsoid	61.4	1	Absent	-
	AMF C 1.4	Brown	Globose	67.4	2	Absent	-
	AMF C 1.5	Yellow	Ellipsoid	150	1	2	Straight
T_2 (*Funneliformis mosseae*)	AMF C 2.1	Brown	Oval	55.2	1	Absent	-
	AMF C 2.2	Yellow	Oval	53.7	1	1	Bulbous
	AMF C 2.3	Black	Globose	45.8	2	Absent	-
	AMF C 2.4	Yellow	Globose	62.4	2	1	Straight
T_3 (*Glomus etunicatum*)	AMF C 3.1	Yellow	Globose	71.6	1	2	Straight
	AMF C 3.2	Yellow	Oval	68.7	1	1	Straight
	AMF C 3.3	Black	Sub globose	66.9	1	1	Bulbous
	AMF C 3.4	Brown	Sub globose	70.7	2	Absent	-
T_4 (*Acaulospora* sp.)	AMF C 4.1	Black	Sub globose	67.7	1	1	Bulbous
	AMF C 4.2	Black	Sub globose	107	1	Absent	-
	AMF C 4.3	Brown	Sub globose	55.2	2	Absent	-
	AMF C 4.4	Yellow	Ellipsoid	44.0	1	Absent	-
T_5 (*Gigaspora* sp.)	AMF C 5.1	Black	Oval	75.8	-	Absent	-
	AMF C 5.2	Black	Sub globose	68.2	-	1	Bulbous
	AMF C 5.3	Brown	Sub globose	52.1	2	Absent	-
	AMF C 5.4	Orange	Globose	72.4	1	Absent	-
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	AMF C 6.1	Yellow	Oval	86.6	1	Absent	-
	AMF C 6.2	Brown	Oval	63.1	2	2	Bulbous
	AMF C 6.3	Brown	Oval	68.7	2	Absent	-
	AMF C 6.4	Brown-black	Sub globose	109	1	>1	Straight

T_7 (POP recommendations of KAU, 2016)	AMF C 7.1	Brown	Globose	111	2	1	Bulbous
	AMF C 7.2	Brown	Globose	98.2	2	Absent	-
	AMF C 7.3	Brown	Globose	67.4	1	Absent	-
	AMF C 7.4	Yellow	Oval	48.7	2	1	Straight
	AMF C 7.5	Black	Sub globose	66.7	1	>1	Straight
T_8 (Organic POP of KAU, 2017)	AMF C 8.1	Brown	Globose	73.6	2	Absent	-
	AMF C 8.2	Yellow	Sub globose	48.9	2	2	Bulbous
	AMF C 8.3	Pale yellow	Ellipsoid	82.4	1	Absent	-
T_9 (Absolute control)	AMF C 9.1	Yellow	Ellipsoid	59.5	1	Absent	-
	AMF C 9.2	Black	Sub globose	69.3	1	Absent	-
	AMF C 9.3	Brown	Oval	69.9	2	1	Bulbous
	AMF C 9.4	Yellow	Sub globose	56.5	2	Absent	-

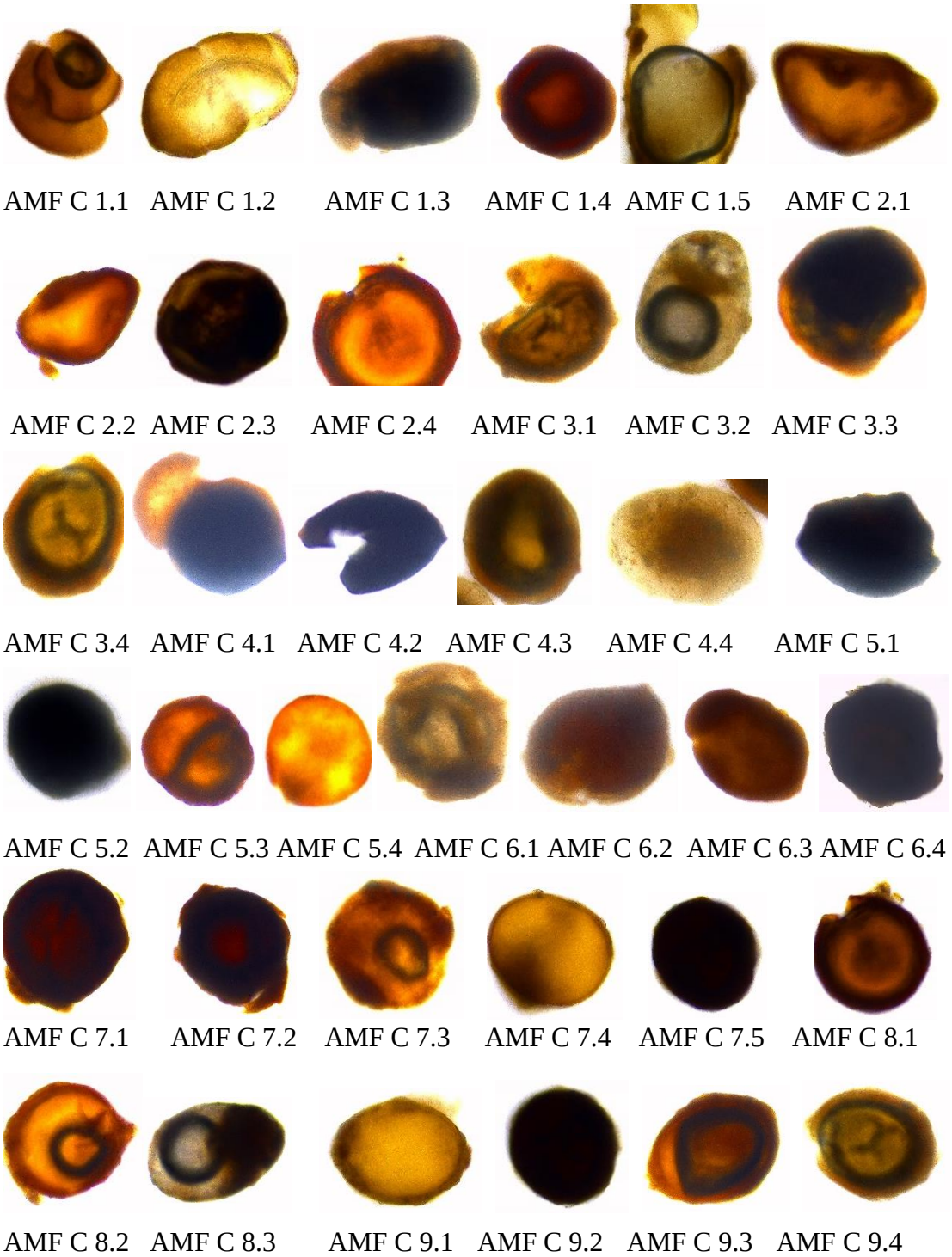


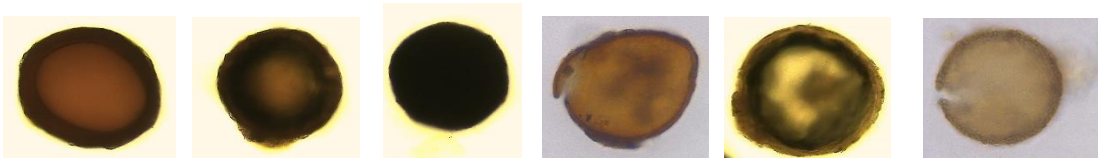
Plate 5. AMF spores isolated from different treatments at 90 DAP (Sept, 2018)

Table 8: Morphological characters of AMF in the rhizosphere soil of Chinese potato at 120 DAP (Oct, 2018)

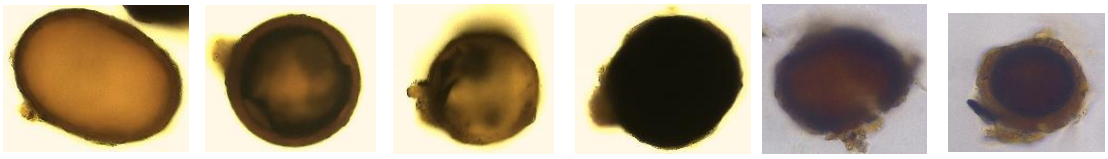
Treatment	Morphological characters of AMF spores						
	Code for morphotypes	Color	Shape	Size (µm)	Spore wall No.	Hypha	
						No.	Characters
T_1 (*Rhizophagus fasciculatus*)	AMF D 1.1	Brown	Sub globose	61.7	2	Absent	-
	AMF D 1.2	Dark brown	Sub globose	49.8	2	1	Bulbous
	AMF D 1.3	Black	Globose	53.9	1	1	Straight
	AMF D 1.4	Pale yellow	Sub globose	60.8	2	Absent	-
	AMF D 1.5	Yellow	Globose	78.2	3	1	Bulbous
	AMF D 1.6	Pale yellow	Globose	57.3	2	Absent	-
T_2 (*Funneliformis mosseae*)	AMF D 2.1	Light brown	Ellipsoid	63.8	2	1	-
	AMF D 2.2	Brown	Sub globose	63.3	2	1	Bulbous
	AMF D 2.3	Light brown	Globose	59.3	2	1	Bulbous
	AMF D 2.4	Black	Sub globose	59.4	1	1	Bulbous
	AMF D 2.5	Brown	Sub globose	60.7	2	2	Straight
	AMF D 2.6	Brown	Globose	37.0	1	1	Straight
	AMF D 2.7	Light brown	Ellipsoid	66.1	2	1	Straight
	AMF D 2.8	Brown	Globose	71.4	-	1	Straight
	AMF D 2.9	Black	Globose	42.6	1	1	Straight
	AMF D 2.10	Brown	Ellipsoid	62.4	2	1	Straight
T_3 (*Glomus etunicatum*)	AMF D 3.1	Yellow	Sub globose	51.8	2	1	Bulbous
	AMF D 3.2	Dark brown	Sub globose	53.8	-	1	Straight
	AMF D 3.3	Brown	Ellipsoid	74.6	-	Absent	-
	AMF D 3.4	Light yellow	Globose	51.8	1	1	Bulbous
	AMF D 3.5	Brown	Globose	74.3	2	1	Bulbous
	AMF D 3.6	yellow	Globose	58.2	1	1	Straight
	AMF D 3.7	Brown	Globose	67.3	2	Absent	-
	AMF D 3.8	Brown	Sub globose	71.7	2	Absent	-

T_4 (*Acaulospora* sp.)	AMF D 4.1	Dark brown	Globose	66.9	2	1	Straight
	AMF D 4.2	Yellow	Globose	50.4	2	Absent	-
	AMF D 4.3	Black	Globose	33.3	1	1	Bulbous
	AMF D 4.4	Yellow	Globose	28.0	2	1	Bulbous
	AMF D 4.5	Black	Sub globose	62.8	1	Absent	-
	AMF D 4.6	Brown	Ellipsoid	89.8	2	Absent	-
T_5 (*Gigaspora* sp.)	AMF D 5.1	Black	Sub globose	40.2	1	1	Straight
	AMF D 5.2	Dark yellow	Oval	56.1	2	1	Bulbous
	AMF D 5.3	Yellow	Oval	62.4	-	1	Bulbous
	AMF D 5.4	Pale yellow	Sub globose	65.6	2	Absent	-
	AMF D 5.5	Dark brown	Globose	71.0	2	Absent	-
	AMF D 5.6	Pale yellow	Sub globose	52.4	-	Absent	-
	AMF D 5.7	Yellow	Globose	37.2	2	1	Straight
	AMF D 5.8	Black	Globose	58.4	1	Absent	
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	AMF D 6.1	Black	Globose	58.5	1	>1	Curled
	AMF D 6.2	Pale yellow	Globose	41.2	2	1	Straight
	AMF D 6.3	Black	Oval	60.5	2	>1	Straight
	AMF D 6.4	Brown	Globose	60.4	2	Absent	-
	AMF D 6.5	Brown	Sub globose	63.6	2	Absent	-
	AMF D 6.6	Black	Sub globose	37.8	1	1	Straight
	AMF D 6.7	Black	Globose	65	1	Absent	-
	AMF D 6.8	Brown	Sub globose	56.1	3	1	Straight
	AMF D 6.9	Pale yellow	Globose	48.3	-	1	Curled
T_7 (POP recommendations of KAU, 2016)	AMF D 7.1	Black	Globose	59.2	1	Absent	-
	AMF D 7.2	Brown	Globose	65.4	2	1	Bulbous
	AMF D 7.3	Brown	Sub globose	50.0	3	1	Straight
	AMF D 7.4	Brown	Sub globose	71.6	3	1	Straight
	AMF D 7.5	Yellow	Sub globose	87.1	2	Absent	-
	AMF D 7.6	Black	Globose	48.7	1	Absent	-
	AMF D 7.7	Yellow	Sub globose	76.3	2	Absent	-
T_8 (Organic POP of KAU, 2017)	AMF D 8.1	Black	Globose	53.0	1	Absent	-
	AMF D 8.2	Yellow	Globose	69.7	2	Absent	-
	AMF D 8.3	yellow	Ellipsoid	63.2	2	Absent	-
	AMF D 8.4	Dark yellow	Sub globose	53.0	-	Absent	-

	AMF D 8.5	black	Sub globose	66.5	1	Absent	-
	AMF D 8.6	Pale yellow	Sub globose	58.2	2	1	Straight
	AMF D 8.7	Brown	Sub globose	50.3	2	Absent	-
T_9 (Absolute control)	AMF D 9.1	Yellow	Globose	76.4		1	Straight
	AMF D 9.2	Black	Globose	74.9	1	Absent	-
	AMF D 9.3	Brown	Sub globose	91.5	2	1	Straight
	AMF D 9.4	Brown	Globose	78.9	2	Absent	-
	AMF D 9.5	Pale yellow	Sub globose	61.0	2	Absent	-
	AMF D 9.6	Brown	Sub globose	57.9	3	1	-



AMF D 1.1 AMF D 1.2 AMF D 1.3 AMF D 1.4 AMF D 1.5 AMF D 1.6



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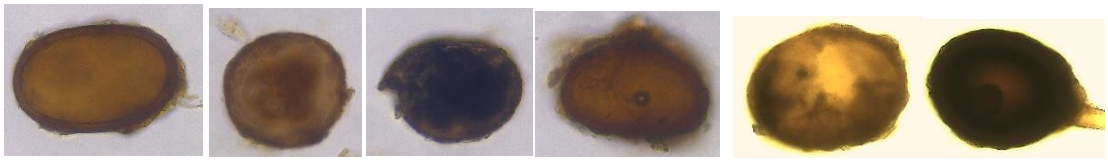
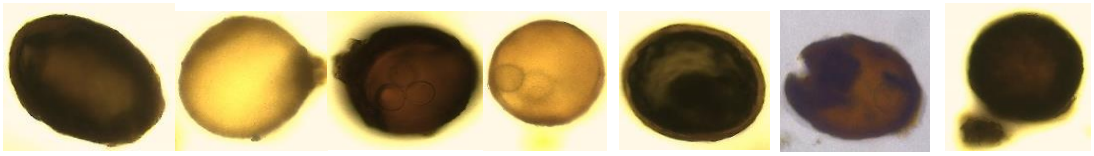
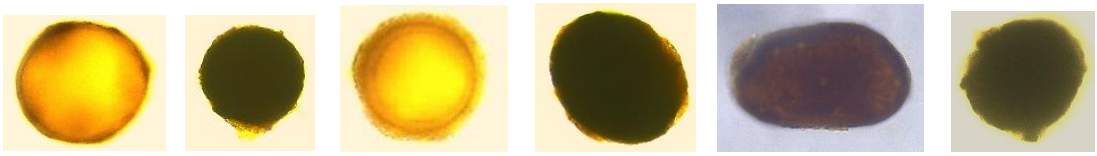


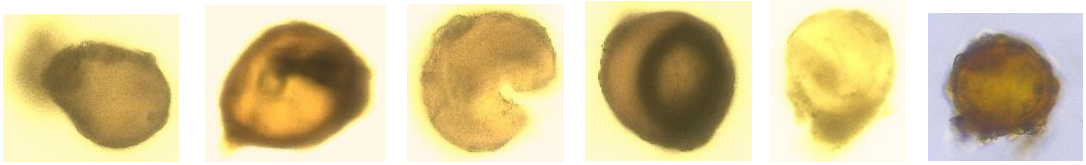
AMF D 2.7 AMF D 2.8 AMF D 2.9 AMF D 2.10 AMF D 3.1 AMF D 3.2



AMF D 3.3 AMF D 3.4 AMF D 3.5 AMF D 3.6 AMF D 3.7 AMF D 3.8 AMF D 4.1

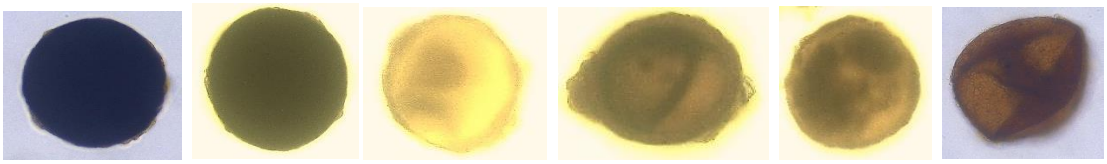


AMF D 4.2 AMF D 4.3 AMF D 4.4 AMF D 4.5 AMF D 4.6 AMF D 5.1

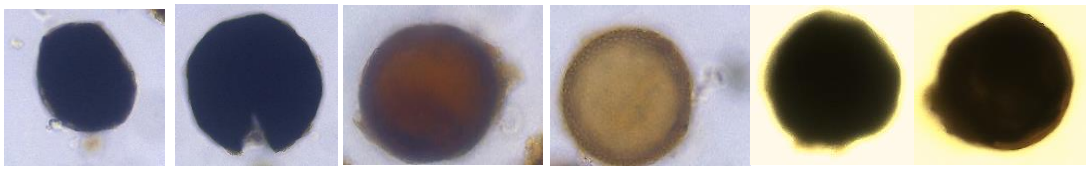


AMF D 5.2 AMF D 5.3 AMF D 5.4 AMF D 5.5 AMF D 5.6 AMF D 5.7

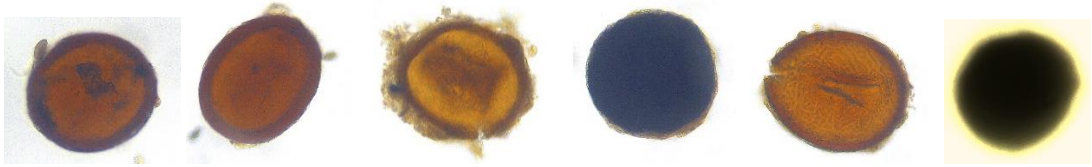
Plate 6. AMF spores isolated from different treatments at 120 DAP (Oct, 2018)



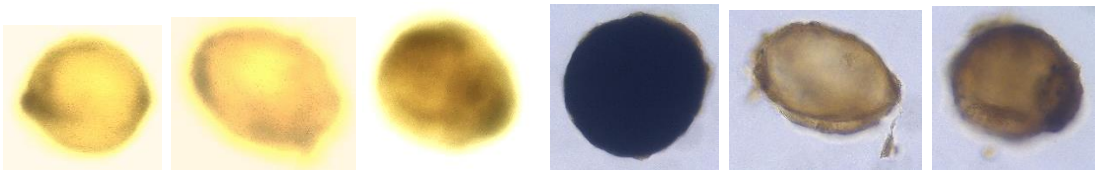
AMF D 5.8 AMF D 6.1 AMF D 6.2 AMF D 6.3 AMF D 6.4 AMF D 6.5



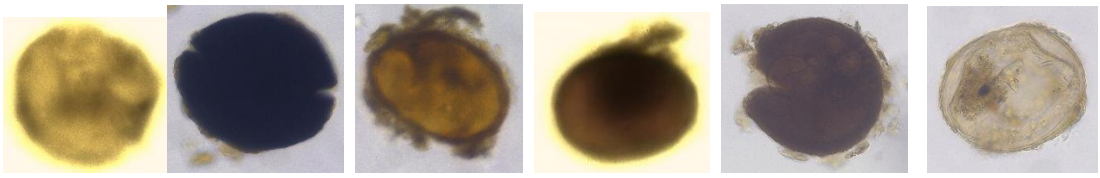
AMF D 6.6 AMF D 6.7 AMF D 6.8 AMF D 6.9 AMF D 7.1 AMF D 7.2



AMF D 7.3 AMF D 7.4 AMF D 7.5 AMF D 7.6 AMF D 7.7 AMF D 8.1



AMF D 8.2 AMF D 8.3 AMF D 8.4 AMF D 8.5 AMF D 8.6 AMF D 8.7



AMF D 9.1 AMF D 9.2 AMF D 9.3 AMF D 9.4 AMF D 9.5 AMF D 9.6

Plate 6. AMF spores isolated from different treatments at 120 DAP (Oct, 2018)

Table 9: Morphological characters of AMF in the rhizosphere soil of Chinese potato at 150 DAP (Nov, 2018)

Treatment	Morphological characters of AMF spores						
	Code for morphotypes	Color	Shape	Size (µm)	Spore wall No.	Hypha	
						No.	Characters
T_1 (*Rhizophagus fasciculatus*)	AMF E 1.1	Yellow	Globose	60.2	2	1	Bulbous
	AMF E 1.2	Brown	Elongated	83.5	2	1	Bulbous
	AMF E 1.3	Brown	Sub globose	53.3	3	Absent	-
	AMF E 1.4	Black	Oval	86.1	1	1	Straight
	AMF E 1.5	Black	Globose	73.3	1	1	Straight
T_2 (*Funneliformis mosseae*)	AMF E 2.1	Brown	Ellipsoid	71.4	2	1	Bulbous
	AMF E 2.2	Dark brown	Ellipsoid	72.1	2	2	Straight
	AMF E 2.3	Yellow	Globose	65.8	2	2	Straight
	AMF E 2.4	Brown	Globose	54.5	3	1	Straight
	AMF E 2.5	Black	Globose	60.8	1	3	Straight
	AMF E 2.6	Yellow	Ellipsoid	78.0	2	1	Straight
	AMF E 2.7	Brown	Sub globose	76.4	3	1	Straight
	AMF E 2.8	Yellow	Globose	63.1	2	1	Bulbous
	AMF E 2.9	Yellow	Oval	64.5	2	1	Bulbous
T_3 (*Glomus etunicatum*)	AMF E 3.1	Black	Sub globose	73.3	1	1	Straight
	AMF E 3.2	Black	Sub globose	50.7	1	Absent	-
	AMF E 3.3	Yellow	Globose	51.3	2	Absent	-
	AMF E 3.4	Yellow	Globose	59.1	3	1	Bulbous
	AMF E 3.5	Yellow	Globose	54.6	2	Absent	-
	AMF E 3.6	Brown	Globose	50.9	3	1	Bulbous
	AMF E 3.7	Pale yellow	Sub globose	65.2	1	Absent	-
T_4 (*Acaulospora* sp.)	AMF E 4.1	Black	Sub globose	62.3	1	1	Straight
	AMF E 4.2	Brown	Ellipsoid	69.1	2	Absent	-
	AMF E 4.3	Dark brown	Globose	59.5	3	Absent	-

	AMF E 4.4	Brown	Oval	75.9	2	1	Straight
	AMF E 4.5	Brown	Globose	71.2	2	1	Straight
T_5 (*Gigaspora* sp.)	AMF E 5.1	Brown	Oval	57.4	3	1	Bulbous
	AMF E 5.2	Brown	Ellipsoid	83.3	3	1	Straight
	AMF E 5.3	Black	Globose	68.9	1	2	Straight
	AMF E 5.4	Yellow	Globose	46.5	2	1	Straight
	AMF E 5.5	Yellow	Globose	47.9	3	1	Bulbous
	AMF E 5.6	Brown	Oval	80.5	2	1	Straight
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	AMF E 6.1	Dark brown	Sub globose	52.2	2	1	Straight
	AMF E 6.2	Brown	Sub globose	47.8	2	Absent	-
	AMF E 6.3	Brown	Globose	76.8	3	Absent	-
	AMF E 6.4	Brown	Oval	61.7	3	1	Bulbous
	AMF E 6.5	Yellow	Globose	59.5	2	1	Bulbous
	AMF E 6.6	Black	Globose	65.2	1	Absent	-
	AMF E 6.7	Yellow	Oval	69.3	2	1	Straight
	AMF E 6.8	Black+ yellow	Oval	71.7-	-	1	Bulbous
T_7 (POP recommendations of KAU, 2016)	AMF E 7.1	Brown	Ellipsoid	76.0	2	1	Bulbous
	AMF E 7.2	Brownish yellow	Sub globose	50.3	2	1	Bulbous
	AMF E 7.3	Black	Sub globose	78.2	-	Absent	-
	AMF E 7.4	Yellow	Sub globose	48.6	2	Absent	
	AMF E 7.5	Brown	globose	66.1	2	Absent	-
T_8 (Organic POP of KAU, 2017)	AMF E 8.8	Black	Globose	75.4	-	1	Straight
	AMF E 8.2	Yellow	Elongated	88.7	1	Absent	-
	AMF E 8.3	Pale yellow	Ellipsoid	98.5	2	Absent	-
	AMF E 8.4	Yellow	Globose	23.8	2	Absent	-
	AMF E 8.5	Brown	Elongated	78.2	2	1	Bulbous
	AMF E 8.6	Brown	Globose	59.8	3	1	Bulbous
T_9 (Absolute control)	AMF E 9.1	Yellow	Globose	62.3	2	1	Straight
	AMF E 9.2	Black	Globose	71.8	-	Absent	-
	AMF E 9.3	Brown	Globose	61.1	3	1	Straight
	AMF E 9.4	Brown	Globose	58.7	3	1	Straight

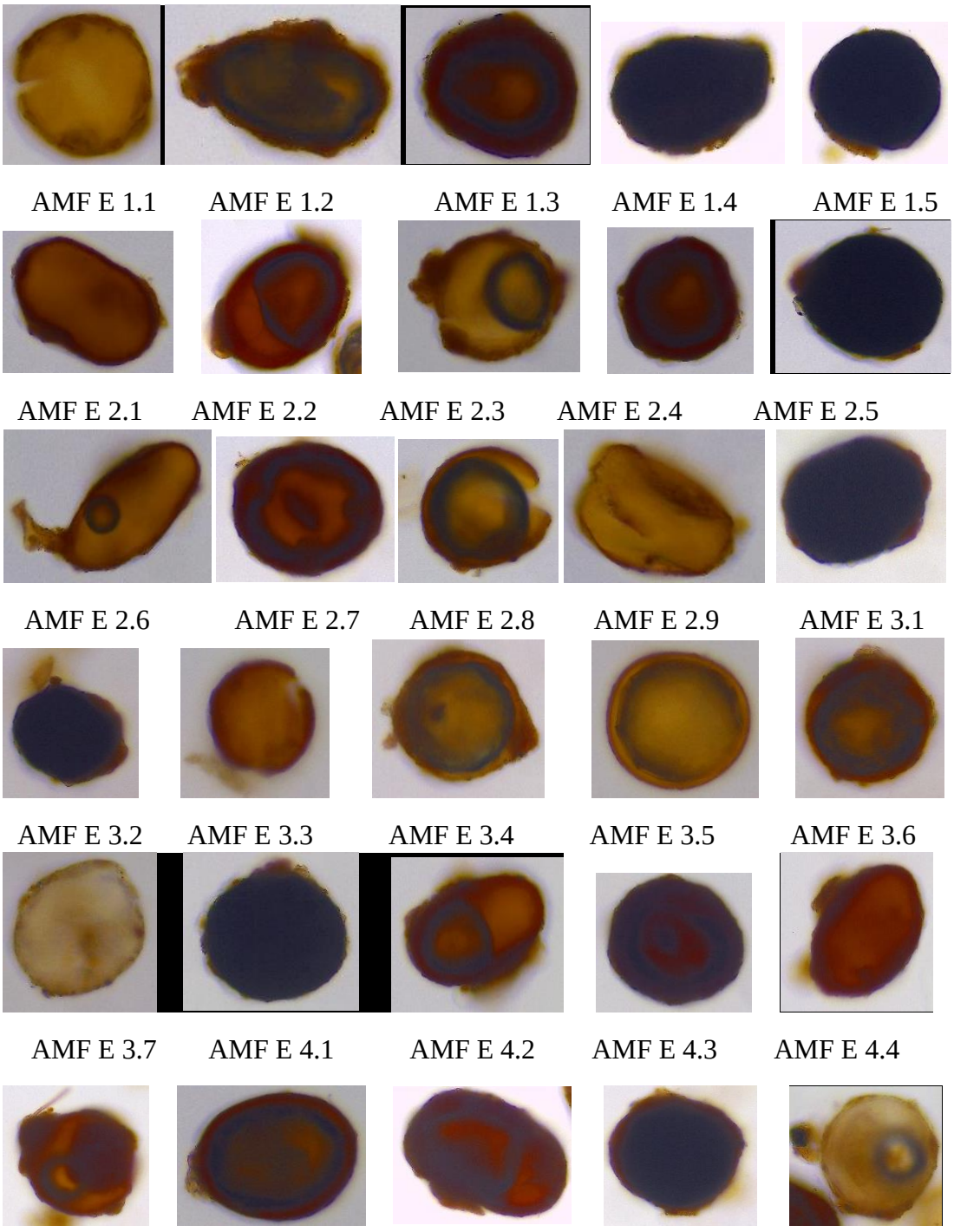
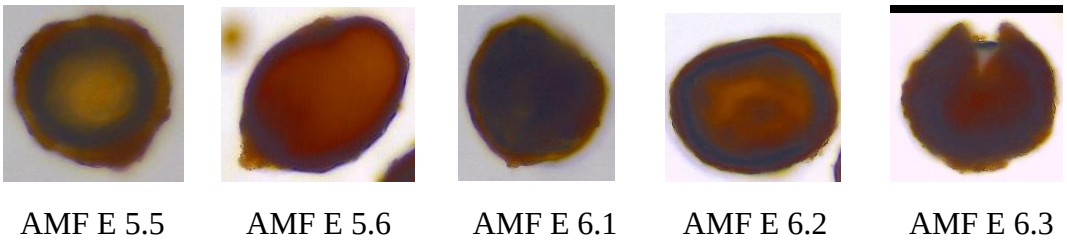
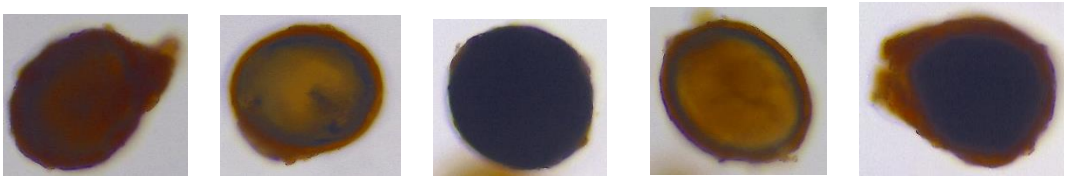


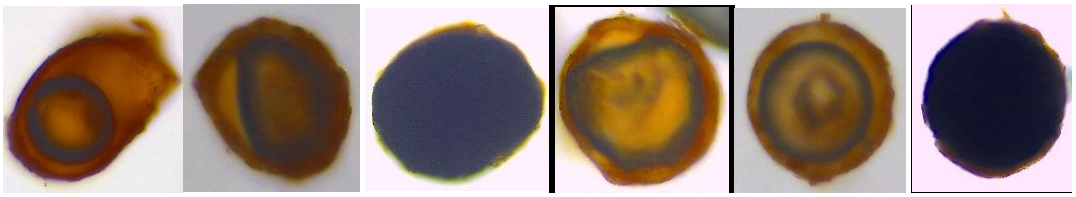
Plate 7. AMF spores isolated from different treatments at 150 DAP (Nov, 2018)



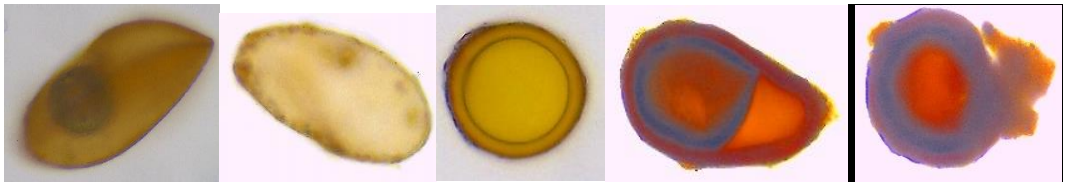
AMF E 5.5 AMF E 5.6 AMF E 6.1 AMF E 6.2 AMF E 6.3



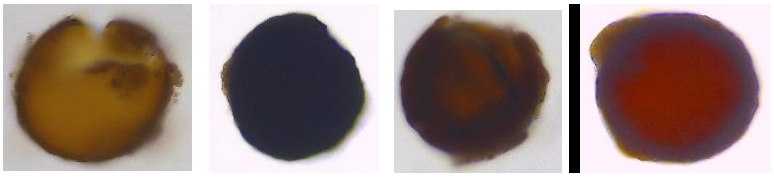
AMF E 6.4 AMF E 6.5 AMF E 6.6 AMF E 6.7 AMF E 6.8



AMF E 7.1 AMF E 7.2 AMF E 7.3 AMF E 7.4 AMF E 7.5 AMF E 8.1



AMF E 8.2 AMF E 8.3 AMF E 8.4 AMF E 8.5 AMF E 8.6



AMF E 9.1 AMF E 9.2 AMF E 9.3 AMF E 9.4

Plate 7. AMF spores isolated from different treatments at 150 DAP (Nov, 2018)

Table 10: Number of AMF morphotypes obtained from different treatments at monthly interval

Treatments	Number of morphotypes obtained				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	12	3	5	6	5
T_2 (*Funneliformis mosseae*)	13	4	4	10	9
T_3 (*Glomus etunicatum*)	7	4	4	8	7
T_4 (*Acaulospora* sp.)	12	3	4	6	5
T_5 (*Gigaspora* sp.)	11	5	4	8	6
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	14	4	4	9	8
T_7 (POP recommendations of KAU, 2016)	11	3	5	7	5
T_8 (Organic POP of KAU, 2017)	11	3	3	7	6
T_9 (Absolute control)	7	4	4	6	4

DAP – Days after planting

4.2.4 Diversity of AMF community in soil

Shannon diversity index of AMF spores in the soil are presented in Table 11.

At 30 DAP, highest spore diversity (H'=2.31) was in T_1 (*Rhizophagus fasciculatus*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) treatment plots. Lowest (H'=1.60) was in absolute control plots.

At 60 DAP, AMF diversity was less and ranged from 0.96 to 1.30. The treatment T_6 (T_1 +T_2 +T_3 +T_4 +T_5)) showed highest species diversity (H'=1.30) and T_4 (*Acaulospora* sp.) treated plots showed lowest (H'=0.89). Absolute control plots had Shannon diversity index 0.99.

The T_1 (*Rhizophagus fasciculatus*) showed highest AMF spore diversity (H'= 1.38) at 90 DAP, followed by T_5 (*Gigaspora* sp.). Least AMF diversity (H'= 1.04) was in T_8 (Organic POP of KAU, 2017). Shannon diversity index of all treatments at 90 DAP was higher as compared to 60 DAP.

At 120 DAP, spore diversity of all the treatments improved, highest (H'= 2.15) was in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and lowest (H'= 1.54) was in T_9 (Absolute control). The diversity index at 120 DAP was higher than 90 DAP, for all treated plots.

The treatments T_2 (*Funneliformis mosseae*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) applied plots showed highest diversity index (H'=1.91) at 150 DAP, absolute control plots showed minimum (H'=1.29). When compared to diversity index at 120 DAP, there was a reduction in AMF spore diversity at 150 DAP.

As a whole, diversity of AMF was more at 30 DAP (H'= 1.60 to 2.31) and less at 60 DAP (H'= 0.96 to 1.30). Among the treatments T_6 (T_1 +T_2 +T_3 +T_4 +T_5) had highest AMF spore diversity.

Table 11: Diversity of AMF spores in the rhizosphere soil at monthly interval

Treatments	Shannon- Wiener diversity index (H')				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	2.31	1.17	1.38	1.61	1.48
T_2 (*Funneliformis mosseae*)	2.11	1.07	1.24	2.13	1.91
T_3 (*Glomus etunicatum*)	1.67	1.01	1.19	1.88	1.72
T_4 (*Acaulospora* sp.)	2.09	0.89	1.31	1.76	1.34
T_5 (*Gigaspora* sp.)	1.87	1.14	1.37	1.84	1.58
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	2.31	1.30	1.24	2.15	1.91
T_7 (POP recommendations of KAU, 2016)	1.65	0.96	1.31	1.91	1.53
T_8 (Organic POP of KAU, 2017)	2.08	0.99	1.04	1.65	1.61
T_9 (Absolute control)	1.60	0.99	1.31	1.54	1.29
Mean	1.97	1.06	1.27	1.83	1.59

DAP – Days after planting

4.3 SOIL PARAMETERS IN DIFFERENT TREATMENTS AT MONTHLY INTERVAL

4.3.1 Mean monthly soil temperature

There were no significant variation in the mean soil temperature (Table 12). Mean monthly soil temperature was high at 120 DAP (28.85^0C) and low at 60 DAP (25.94^0C). Highest monthly mean temperature (28.87^0C) was recorded in T_2 (*Funneliformis mosseae*) and T_5 (*Gigaspora* sp.) at 120 DAP, and lowest monthly mean temperature (25.92^0C) was recorded in T_7 (POP recommendations of KAU, 2016) at 30 DAP.

4.3.2 Soil moisture

Soil moisture were recorded at monthly interval (Table 13). At the time of planting 15% soil moisture was recorded. An increased soil moisture percent was recorded in all the treatments at 30 DAP and 60 DAP. However the treatment recorded low soil moisture percent at 90 DAP (7.13%). Highest soil moisture (11.87%) was recorded in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) at 30 DAP and lowest (6.15%) was in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) at 150 DAP.

4.3.3 Soil pH

Soil pH of the experimental site at the start of the experiment was 4.6. Soil pH was recorded at monthly interval (Table 14). Soil pH was recorded highest at 30 DAP and lowest at 150 DAP. At the time of harvest, soil pH were more acidic (3.81) than other months. On the whole highest pH (5.07) of the experiment was recorded in T_8 (Organic POP of KAU, 2017) at 30 DAP and lowest (3.5) was in T_1 (*Rhizophagus fasciculatus*) at 150 DAP.

Table 12: Mean monthly soil temperature at monthly interval under field condition

Treatments	Soil temperature (^{0}C)				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	27.03	25.95	26.42	28.84	28.04
T_2 (*Funneliformis mosseae*)	27.01	25.94	26.59	28.87	28.05
T_3 (*Glomus etunicatum*)	27.02	25.94	26.92	28.83	28.06
T_4 (*Acaulospora* sp.)	27.04	25.95	26.45	28.86	28.03
T_5 (*Gigaspora* sp.)	27.03	25.95	26.44	28.87	28.05
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	27.06	25.97	26.13	28.86	28.06
T_7 (POP recommendations of KAU, 2016)	27.03	25.92	26.45	28.85	28.03
T_8 (Organic POP of KAU, 2017)	27.04	25.96	26.48	28.85	28.04
T_9 (Absolute control)	26.99	25.97	26.49	28.83	28.06
CD	NS	NS	NS	NS	NS

DAP – Days after planting

Table 13: Soil moisture at monthly interval under field condition

Treatments	Soil moisture (%)				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct,2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	11.39	10.37^{bc}	7.74	9.04^{c}	7.92^{ab}
T_2 (*Funneliformis mosseae*)	11.13	11.42^{ab}	6.58	9.48^{bc}	8.04^{a}
T_3 (*Glomus etunicatum*)	9.92	10.49^{bc}	7.81	9.15^{bc}	6.39^{cd}
T_4 (*Acaulospora* sp.)	11.77	9.44^{cd}	6.76	10.63^{a}	7.11^{bc}
T_5 (*Gigaspora* sp.)	11.39	11.63^{a}	7.42	9.78^{b}	7.98^{a}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	11.87	9.59^{cd}	7.25	9.55^{bc}	6.15^{d}
T_7 (POP recommendations of KAU, 2016)	9.74	9.81^{cd}	6.72	9.15^{bc}	7.44^{ab}
T_8 (Organic POP of KAU, 2017)	10.12	9.48^{cd}	6.79	9.55^{bc}	7.44^{ab}
T_9 (Absolute control)	10.52	9.26^{d}	7.11	9.38^{bc}	7.62^{ab}
CD	NS	1.06	NS	0.67	0.81

DAP – Days after planting

Table 14: Soil pH at monthly interval under field condition

Treatments	Soil pH				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	4.80	4.59^{abc}	4.92^{a}	4.45^{b}	3.50^{d}
T_2 (*Funneliformis mosseae*)	4.94	4.42^{d}	4.74^{b}	4.41^{b}	3.70^{cd}
T_3 (*Glomus etunicatum*)	4.96	4.45^{cd}	4.61^{bcd}	4.48^{b}	3.80^{c}
T_4 (*Acaulospora* sp.)	4.98	4.50^{abcd}	4.57^{bcd}	4.44^{b}	3.70^{cd}
T_5 (*Gigaspora* sp.)	4.94	4.47^{bcd}	4.59^{bcd}	4.40^{b}	3.90^{bc}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	5.04	4.65^{a}	4.53^{cd}	4.42^{b}	3.70^{cd}
T_7 (POP recommendations of KAU, 2016)	4.96	4.42^{d}	4.48^{d}	4.45^{b}	3.70^{cd}
T_8 (Organic POP of KAU, 2017)	5.07	4.63^{ab}	4.62^{bcd}	4.72^{a}	4.10^{ab}
T_9 (Absolute control)	4.83	4.66^{a}	4.69^{bc}	4.80^{a}	4.20^{a}
CD	NS	0.16	0.17	0.19	0.29

DAP – Days after planting Initial pH= 4.6

4.4 MICROBIAL ACTIVITIES IN SOIL AT MONTHLY INTERVAL

4.4.1 Dehydrogenase activity

Dehydrogenase activity in soil were recorded at monthly interval (Table 15).

Dehydrogenase enzyme activity varied significantly among the treatments. At 30 DAP, highest dehydrogenase activity (28.81 µg TPF day^{-1} g^{-1} soil) was observed in T_1 (*Rhizophagus fasciculatus*), which was on par with all other AMF inoculated treatments except T_4 (*Acaulospora* sp.). Dehydrogenase activity was lower in T_9 (Absolute control) and T_8 (Organic POP of KAU, 2017) with 17.16 µg TPF day^{-1} g^{-1} soil and 17.73 µg TPF day^{-1} g^{-1} soil respectively.

At 60 DAP, T_2 (*Funneliformis mosseae*) recorded highest dehydrogenase activity (25.49 µg TPF day^{-1} g^{-1} soil) followed by T_6 (T_1 +T_2 +T_3 +T_4 +T_5) with 23.52 49 µg TPF day^{-1} g^{-1} soil. T_8 (Organic POP of KAU, 2017) and absolute control plots showed lowest dehydrogenase activity (17.61 µg TPF day^{-1} g^{-1} soil and 15.64 µg TPF day^{-1} g^{-1} soil respectively). Dehydrogenase activity at 60 DAP were less than 30 DAP.

The treatment T_1 (*Glomus etunicatum*) treated plots had highest dehydrogenase activity (29.86 µg TPF day^{-1} g^{-1} soil) at 90 DAP, which was on par with T_2 (*Funneliformis mosseae*), T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and T_7 (POP recommendations of KAU, 2016). Lowest dehydrogenase activity (17.36 µg TPF day^{-1} g^{-1} soil) was recorded in absolute control plot.

Dehydrogenase activity at 120 DAP was less than at 90 DAP, with an exception in T_6 (T_1 +T_2 +T_3 +T_4 +T_5). At 120 DAP, T_6 (T_1 +T_2 +T_3 +T_4 +T_5) had highest dehydrogenase activity (29.31 µg TPF day^{-1} g^{-1} soil) followed by T_2 (*Funneliformis mosseae*) and absolute control (T_9) recorded the lowest (15.89 31 µg TPF day^{-1} g^{-1} soil).

Table 15: Dehydrogenase activity in soil at monthly interval under field condition

Treatments	Dehydrogenase activity (µg TPF day^{-1} g^{-1} soil)				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	28.81^{a}	21.92^{abc}	22.49^{bcd}	20.19^{bc}	25.92^{a}
T_2 (*Funneliformis mosseae*)	27.39^{ab}	25.49^{a}	28.33^{ab}	23.85^{ab}	27.11^{a}
T_3 (*Glomus etunicatum*)	27.10^{ab}	21.31^{bcd}	29.86^{a}	20.54^{bc}	23.72^{a}
T_4 (*Acaulospora* sp.)	22.84^{bc}	19.46^{cde}	20.89^{cd}	16.55^{c}	26.11^{a}
T_5 (*Gigaspora* sp.)	27.39^{ab}	20.19^{bcd}	25.02^{abc}	19.04^{bc}	23.81^{a}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	27.10^{ab}	23.52^{ab}	28.92^{a}	29.31^{a}	27.68^{a}
T_7 (POP recommendations of KAU, 2016)	22.56^{bcd}	21.19^{bcd}	28.68^{a}	25.00^{ab}	23.32^{a}
T_8 (Organic POP of KAU, 2017)	17.73^{cd}	17.61^{de}	18.66^{d}	16.55^{c}	17.77^{b}
T_9 (Absolute control)	17.16^{d}	15.64^{e}	17.36^{d}	15.89^{c}	17.37^{b}
CD(0.05)	5.66	4.00	6.12	6.52	4.45

DAP – Days after planting

At 150 DAP, highest dehydrogenase activity (27.68 µg TPF day^{-1} g^{-1} soil) was recorded in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and it was on par with all other treatments except T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control).

As a whole, T_2 (*Funneliformis mosseae*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) had highest dehydrogenase activity during the experiment. T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) were found to be with lowest dehydrogenase activity.

4.4.2 Carbon dioxide evolution in soil at monthly interval

Soil respiration (CO_2 evolution) were determined at monthly interval (Table 16). Carbon dioxide evolution was highest (0.36 mg CO_2 g^{-1} soil) in T_4 (*Acaulospora* sp.) and it was on par with the all other AMF treatments. The lowest soil respiration (0.17 mg CO_2 g^{-1} soil) was in the case of T_9 (Control), followed by T_8 (Organic POP of KAU, 2017).

At 60 DAP, there was a reduction in CO_2 evolution compared to 30 DAP. AMF inoculated plots recorded increased CO_2 evolution. T_2 (*Funneliformis mosseae*) treated plot showed highest (0.25 mg CO_2 g^{-1} soil) CO_2 evolution at 60 DAP, followed by T_3 (*Glomus etunicatum*) and T_5 (*Gigaspora* sp.). Absolute control plot had lowest rate of soil respiration (0.11 mg CO_2 g^{-1} soil).

The CO_2 evolution at 90 DAP was higher than 60 DAP. AT 90 DAP, T_1 (*Rhizophagus fasciculatus*) treated plots released 0.36 mg CO_2 g^{-1} soil, followed by T_6 (T_1 +T_2 +T_3 +T_4 +T_5). CO2 evolution was lowest (0.22 mg CO_2 g^{-1} soil) in case of T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control).

Rate of soil respiration at 120 DAP was high for all treated plants, which ranged between 0.73- 0.96 mg CO_2 g^{-1} soil for T_9 (Absolute control) and T_5 (*Gigaspora* sp.) respectively.

Table 16: Carbon dioxide evolution in soil at monthly interval under field condition

Treatments	Carbon dioxide evolution (mg CO_2 g^{-1} soil)				
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**	**150 DAP (Nov, 2018)**
T_1(*Rhizophagus fasciculatus*)	0.30^{a}	0.18^{bcd}	0.36^{a}	0.85^{bcd}	0.70^{a}
T_2 (*Funneliformis mosseae*)	0.32^{a}	0.25^{a}	0.25^{bc}	0.88^{abc}	0.57^{bc}
T_3 (*Glomus etunicatum*)	0.28^{ab}	0.23^{ab}	0.26^{bc}	0.73^{e}	0.62^{ab}
T_4 (*Acaulospora* sp.)	0.36^{a}	0.18^{bcd}	0.23^{bc}	0.91^{ab}	0.60^{bc}
T_5 (*Gigaspora* sp.)	0.28^{ab}	0.21^{abc}	0.23^{bc}	0.96^{a}	0.52^{c}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	0.34^{a}	0.19^{abc}	0.30^{ab}	0.78^{cde}	0.55^{bc}
T_7 (POP recommendations of KAU, 2016)	0.21^{bc}	0.15^{cd}	0.23^{bc}	0.76^{de}	0.52^{c}
T_8 (Organic POP of KAU, 2017)	0.18^{c}	0.12^{de}	0.22^{c}	0.74^{e}	0.52^{c}
T_9 (Absolute control)	0.17^{c}	0.11^{e}	0.22^{c}	0.73^{e}	0.37^{d}
CD (0.05)	0.095	0.061	0.070	0.106	0.94

DAP – Days after planting

At the time of harvest, highest CO_2 evolution was observed in T_1 (*Rhizophagus fasciculatus*) and lowest was in T_9 (Absolute control).

As a whole, soil respiration from the AMF treated plots was more than non AMF plots.

4.4.3 Acid phosphatase enzyme activity

Acid phosphatase activity were determined at monthly interval (Table 17).

Acid phosphatase activity was not significantly different between different treatments at 30, 60 and 120 DAP. However, acid phosphatase activity varied between the months. Acid phosphatase activity was highest at 120 DAP, and lowest at 60 DAP.

The T_2 treatment (*Funneliformis mosseae*) recorded highest acid phosphatase enzyme activity (19.43 µg PNP g^{-1} h^{-1}) at 90 DAP, which was on par with all other treatments except absolute control. The absolute control plot recorded lowest acid phosphatase activity of 16.33 µg PNP g^{-1} h^{-1}.

At 150 DAP, T_2 (*Funneliformis mosseae*) showed highest acid phosphatase activity (21.35 µg PNP g^{-1} h^{-1}). However, T_9 (Absolute control) recorded lowest (13.62 µg PNP g^{-1} h^{-1}) followed by T_8 (Organic POP of KAU, 2017).

4.5 BIOMETRIC CHARACTERS OF CHINESE POTATO PLANT, TUBER YIELD AND PHOSPHORUS UPTAKE AS INFLUENCED BY DIFFERENT AMF

4.5.1 Plant height

The result pertaining to plant height by different treatments at monthly interval are presented in Table 18.

Table 17: Acid phosphatase activity in soil at monthly interval under field condition

Treatments	Acid phosphatase activity (µg PNP g^{-1} h^{-1})				
	30 DAP (July, 2018)	60 DAP (Aug, 2018)	90 DAP (Sept, 2018)	120 DAP (Oct, 2018)	150 DAP (Nov, 2018)
T_1(*Rhizophagus fasciculatus*)	17.76	16.11	19.09[a]	28.63	17.42[bc]
T_2 (*Funneliformis mosseae*)	19.27	16.27	19.43[a]	28.47	21.35[a]
T_3 (*Glomus etunicatum*)	18.15	16.05	19.05[a]	30.10	18.97[ab]
T_4 (*Acaulospora* sp.)	18.38	16.47	18.56[a]	26.76	17.27[bc]
T_5 (*Gigaspora* sp.)	18.33	16.81	18.97[a]	26.02	16.49[bcd]
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	18.81	16.88	18.93[a]	27.57	17.66[bc]
T_7 (POP recommendations of KAU, 2016)	18.15	16.48	18.45[a]	28.79	15.86[bcd]
T_8 (Organic POP of KAU, 2017)	17.62	16.13	18.79[a]	26.59	15.17[cd]
T_9 (Absolute control)	17.57	16.11	16.33[b]	26.51	13.62[d]
CD	NS	NS	1.51	NS	3.27

DAP – Days after planting

Table 18: Effect of different treatments on plant height of Chinese potato at monthly interval

Treatments	Plant height (cm)			
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**
T_1(*Rhizophagus fasciculatus*)	9.47	28.13[a]	50.07[a]	64.40[ab]
T_2 (*Funneliformis mosseae*)	8.93	27.00[a]	49.80[ab]	69.20[ab]
T_3 (*Glomus etunicatum*)	9.07	26.13[a]	47.40[b]	66.53[ab]
T_4 (*Acaulospora* sp.)	9.60	27.53[a]	49.80[ab]	68.87[ab]
T_5 (*Gigaspora* sp.)	9.27	26.60[a]	48.60[b]	61.20[b]
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	8.87	27.73[a]	48.60[b]	68.47[ab]
T_7 (POP recommendations of KAU, 2016)	10.33	28.00[a]	48.13[b]	70.53[a]
T_8 (Organic POP of KAU, 2017)	9.20	16.73[b]	22.33[c]	27.93[c]
T_9 (Absolute control)	9.33	14.40[b]	19.13[d]	21.53[c]
CD(0.05)	NS	3.59	2.98	8.98

DAP – Days after planting

The effect of treatments were not significantly different in plant height at 30 DAP. However on later stages, significant difference in plant height were seen.

At 60 DAP, T_1 (*Rhizophagus fasciculatus*) had highest plant height (28.13 cm), which was on par with all other treatments except in T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control).

The T_1 (*Rhizophagus fasciculatus*) had highest plant height (50.07 cm) at 90 DAP, followed by T_2 (*Funneliformis mosseae*) and T_4 (*Acaulospora* sp.). Shortest plants were recorded in the treatments T_9 (Absolute control) and T_8 (Organic POP of KAU, 2017) with 19.13 cm and 22.33 cm respectively.

The T_7 (POP recommendations of KAU, 2016) had highest plant height (70.53 cm) at 120 DAP, which was followed by T_2 (*Funneliformis mosseae*) and T_4 (*Acaulospora* sp.). Plants of absolute control plots were the shortest (21.53 cm).

The plant height of T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) treatments were significantly lower throughout the growing season, except at 30 DAP.

4.5.2 Root biomass

The root biomass of the Chinese potato plants were recorded at monthly interval (Table 19).

Among the treatments, root biomass were highest (5.19 g) in T_4 (*Acaulospora* sp.), which was on par with T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*) and T_7 (POP recommendations of KAU, 2016). Root biomass were lowest (4.62 g) in absolute control plants at 30 DAP.

At 60 DAP, root biomass production were highest (14.75 g) in T_2 (*Funneliformis mosseae*), which was on par with all other AMF treatments. T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) had lower root

biomass (7.31g and 5.92 g respectively).

The highest root biomass at 90 DAP were recorded in T_7 (POP recommendations of KAU, 2016), which was on par with all other treatments except T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control).

At 120 DAP, highest root biomass (36.88 g) was recorded in T_2 (*Funneliformis mosseae*), followed by T_4 (*Acaulospora* sp.). Root biomass were lowest (10.60 g) in absolute control plants.

As a whole, T_2 (*Funneliformis mosseae*) and T_4 (*Acaulospora* sp.) showed superior influence on root biomass of Chinese potato during the entire growing season. T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) were poor in root biomass production.

4.5.3 Dry weight of plant

The dry weight of Chinese potato plants at monthly interval are given in the Table 20. There was significant difference among the treatments on dry matter production of Chinese potato plants.

At 30 DAP, highest dry matter production (4.43 g/ plant) was recorded in T_5 (*Gigaspora* sp.) followed by T_1 (*Rhizophagus fasciculatus*). Absolute control plants were lowest (3.32 g/ plant)

At 60 DAP, T_1 (*Rhizophagus fasciculatus*) treated plants recorded highest dry matter production (12.77 g/ plant), followed by T_6 (T_1 +T_2 +T_3 +T_4 +T_5). T_9 (Absolute control) plants were poorest (5.89 g/ plant) in dry matter production.

The T_1 (*Rhizophagus fasciculatus*) had highest dry matter production (28.99 g/ plant) at 90 DAP (28.99 g/ plant) and it was on par with T_2 (*Funneliformis mosseae*). Lowest dry matter production (9.57 g/ plant) was in T_9 (Absolute control).

The T_2 (*Funneliformis mosseae*) treated plants were recorded with

Table 19: Effect of different treatments on root biomass of Chinese potato at monthly interval

Treatments	Root biomass (g)/ plant			
	30 DAP (July, 2018)	60 DAP (Aug, 2018)	90 DAP (Sept, 2018)	120 DAP (Oct, 2018)
T_1(*Rhizophagus fasciculatus*)	5.12^{ab}	13.70^{ab}	17.46^{a}	22.17^{bc}
T_2 (*Funneliformis mosseae*)	5.05^{ab}	14.75^{a}	18.39^{a}	36.88^{a}
T_3 (*Glomus etunicatum*)	5.00^{b}	12.92^{ab}	19.20^{a}	19.00^{cd}
T_4 (*Acaulospora* sp.)	5.19^{a}	14.39^{ab}	18.27^{a}	34.12^{a}
T_5 (*Gigaspora* sp.)	5.01^{b}	11.71^{abc}	19.56^{a}	24.65^{b}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	4.99^{bc}	14.03^{ab}	19.13^{a}	22.77^{bc}
T_7 (POP recommendations of KAU, 2016)	5.07^{ab}	9.67^{bcd}	19.60^{a}	23.46^{bc}
T_8 (Organic POP of KAU, 2017)	4.86^{c}	7.31^{cd}	11.13^{b}	15.27^{de}
T_9 (Absolute control)	4.62^{d}	5.92^{d}	8.89^{b}	10.60^{e}
CD(0.05)	0.14	4.98	3.04	5.11

DAP – Days after planting

T_1 (*Rhizophagus fasciculatus*)

T_2 (*Funneliformis mosseae*)

T_3 (*Glomus etunicatum*)

T_4 (*Acaulospora* sp.)

T_5 (*Gigaspora* sp.)

T_6 (T_1 +T_2 +T_3 +T_4 +T_5)

T_7 (POP recommendations of KAU, 2016)

T_8 (Organic POP of KAU, 2017)

T_9 (Absolute control)

Plate 8. Root biomass of chinese potato from different treatments at 120 DAP (Oct, 2018)

Table 20: Effect of different treatments on dry weight of Chinese potato plants at monthly interval

Treatments	Dry weight of plant (g)			
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**
T_1(*Rhizophagus fasciculatus*)	3.84^{b}	12.77^{a}	28.99^{a}	51.52^{bc}
T_2 (*Funneliformis mosseae*)	3.71^{bc}	9.31^{cd}	28.86^{a}	66.41^{a}
T_3 (*Glomus etunicatum*)	3.55^{bcd}	10.29^{bc}	24.18^{cd}	57.29^{b}
T_4 (*Acaulospora* sp.)	3.36^{cd}	10.54^{b}	26.19^{b}	58.68^{b}
T_5 (*Gigaspora* sp.)	4.43^{a}	9.22^{d}	21.93^{e}	48.46^{c}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	3.53^{bcd}	10.66^{b}	25.43^{bc}	46.94^{c}
T_7 (POP recommendations of KAU, 2016)	3.54^{bcd}	8.55^{d}	23.66^{d}	49.17^{c}
T_8 (Organic POP of KAU, 2017)	3.54^{bcd}	7.19^{e}	15.11^{f}	32.47^{d}
T_9 (Absolute control)	3.26^{d}	5.89^{f}	9.57^{g}	23.56^{e}
CD(0.05)	0.37	0.99	1.72	7.69

DAP – Days after planting

highest dry matter content (66.41 g) followed by T_4 (*Acaulospora* sp.) and T_3 (*Glomus etunicatum*). Lowest dry matter production (23.56 g/ plant) was in T_9 (Absolute control).

4.5.4 Days taken for first flowering

The number of days taken for first flowering under different treatments are given in Table 21.

The number of days taken for first flowering varied between 88 to 91 days. T_7 (POP recommendations of KAU, 2016) recorded minimum days for first flowering (88 days). None of the treatments showed significant differences. The maximum number of days taken for first flowering (91 days) was in case of T_8 (Organic POP of KAU, 2017).

4.5.5 Tuber yield

Per plant yield of Chinese potato tubers weighed from five observation plants and mean yield of each treatments are presented in Table 22.

Per plant yield from T_2 (*Funneliformis mosseae*) was highest (146.87 g) followed by T_7 (POP recommendations of KAU, 2016) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5). T_9 (Absolute control) and T_8 (Organic POP of KAU, 2017) had lowest per plant yield, 52.20 g and 81.73 g respectively.

Highest tuber yield (16.98 t ha^{-1}) were recorded in the treatment T_6 (T_1 +T_2 +T_3 +T_4 +T_5), which was on par with T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_7 (POP recommendations of KAU, 2016). Among the AMF treatments T_3 (*Glomus etunicatum*) and T_5 (*Gigaspora* sp.) had lower tuber yield (12.03 t ha^{-1} and 14.24 t ha^{-1} respectively). Weight of the tubers from T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) were lowest (6.96 t ha^{-1} and 6.53 t ha^{-1} respectively).

Table 21: Effect of different treatments on the number of days taken for first flowering in Chinese potato plants

Treatments	Days
T_1(*Rhizophagus fasciculatus*)	88
T_2 (*Funneliformis mosseae*)	90
T_3 (*Glomus etunicatum*)	89
T_4 (*Acaulospora* sp.)	88
T_5 (*Gigaspora* sp.)	90
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	89
T_7 (POP recommendations of KAU, 2016)	88
T_8 (Organic POP of KAU, 2017)	91
T_9 (Absolute control)	91
CD(0.05)	NS

Table 22: Effect of different treatments on tuber yield of Chinese potato

Treatments	Tuber yield (g/ plant)	Tuber yield (t ha^{-1})
T_1(*Rhizophagus fasciculatus*)	115.73^{ab}	15.68^{ab}
T_2 (*Funneliformis mosseae*)	146.87^{a}	16.04^{ab}
T_3 (*Glomus etunicatum*)	107.00^{ab}	12.03^{c}
T_4 (*Acaulospora* sp.)	129.07^{a}	15.82^{ab}
T_5 (*Gigaspora* sp.)	127.13^{ab}	14.24^{bc}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	135.40^{a}	16.98^{a}
T_7 (POP recommendations of KAU, 2016)	144.93^{a}	16.68^{ab}
T_8 (Organic POP of KAU, 2017)	81.73^{bc}	6.96^{d}
T_9 (Absolute control)	52.20^{c}	6.53^{d}
CD(0.05)	0.562	2.48

T_2 (*Funneliformis mosseae*)

T_6 (T_1 +T_2 +T_3 +T_4 +T_5)

T_7 (POP recommendations of KAU, 2016)

T_9 (Absolute control)

Plate 9. Tuber yield of chinese potato from different treatments

4.6 PHOSPHORUS UPTAKE

The phosphorus uptake by Chinese potato plants at monthly interval are furnished in Table 23.

Phosphorus uptake by Chinese potato plant were significantly different among treatments. The T_2 (*Funneliformis mosseae*) recorded highest P uptake (3.28 kg ha^{-1}) in Chinese potato at 30 DAP, followed by T_1 (*Rhizophagus fasciculatus*) and T_3 (*Glomus etunicatum*). Lowest P uptake (1.27 kg ha^{-1}) at 30 DAP was recorded in T_9 (Absolute control), followed by T_7 (POP recommendations of KAU, 2016).

At 60 DAP, T_1 (*Rhizophagus fasciculatus*) treated plants were superior in P uptake (13.52 kg ha^{-1}), followed by T_2 (*Funneliformis mosseae*) and T_3 (*Glomus etunicatum*). T_9 (Absolute control) was poor in P uptake (3.55 kg ha^{-1}).

The T_2 treated plants showed increased uptake of P (16.72 kg ha^{-1}) at 90 DAP, and it was on par with T_1 (*Rhizophagus fasciculatus*), which recorded 16.28 kg ha^{-1} P uptake. Absolute control plants were recorded lowest P uptake (6.01 kg ha^{-1}).

At 120 DAP, highest P uptake (60.06 kg ha^{-1}) was recorded from the plants of T_2 (*Funneliformis mosseae*), followed by T_3 (*Glomus etunicatum*) and T_4 (*Acaulospora* sp.) with P uptake of 47.85 kg ha^{-1} and 47.43 kg ha^{-1} respectively. Uptake of P was lowest (8.88 kg ha^{-1}) in T_9 (Absolute control), followed by T_8 (Organic POP of KAU, 2017).

As a whole, T_2 (*Funneliformis mosseae*) recorded highest P uptake among the treatments. P uptake of T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) were poor as compared to other treatments during the experiment.

Table 23: Effect of different treatments on phosphorus uptake by Chinese potato plants at monthly interval

Treatments	Phosphorus uptake (kg ha^{-1})			
	30 DAP (July, 2018)	**60 DAP (Aug, 2018)**	**90 DAP (Sept, 2018)**	**120 DAP (Oct, 2018)**
T_1(*Rhizophagus fasciculatus*)	2.94^{a}	13.52^{a}	16.28^{a}	39.00^{bc}
T_2 (*Funneliformis mosseae*)	3.28^{a}	9.28^{b}	16.72^{a}	60.06^{a}
T_3 (*Glomus etunicatum*)	2.31^{b}	9.23^{b}	11.55^{b}	47.85^{b}
T_4 (*Acaulospora* sp.)	1.77^{cd}	8.60^{b}	10.63^{b}	47.43^{b}
T_5 (*Gigaspora* sp.)	2.03^{bc}	5.77^{cd}	10.84^{b}	33.93^{c}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	1.73^{cd}	9.19^{b}	10.83^{b}	33.87^{c}
T_7 (POP recommendations of KAU, 2016)	1.61^{cd}	7.59^{bc}	13.02^{b}	33.91^{c}
T_8 (Organic POP of KAU, 2017)	2.09^{bc}	5.12^{de}	10.82^{b}	13.33^{d}
T_9 (Absolute control)	1.27^{d}	3.55^{e}	6.01^{c}	8.88^{d}
CD(0.05)	0.53	2.14	2.67	9.85

DAP – Days after planting

4.7 NEMATODE POPULATION IN SOIL

Nematode count before the start of the experiment was 2443 nematodes per 250 g of soil. Nematode population in the soil was significantly different among the treatments (Table 24).

Plant parasitic nematodes were highest (2497 nematodes per 250 g soil) in T_9 (Absolute control), and which was on par with T_8 (Organic POP of KAU, 2017). Least number of plant parasitic nematodes (506.67 nematodes per 250 g soil) were reported in T_6 (T_1 +T_2 +T_3 +T_4 +T_5), which was on par with T_1 (*Rhizophagus fasciculatus*) and T_4 (*Acaulospora* sp.).

Saprophytic nematodes were highest (78 nematodes per 250 g soil) in T_8 (Organic POP of KAU, 2017), followed by T_9 (Absolute control). Number of Saprophytic nematodes were lowest (21 nematodes per 250 g soil) in T_1 (*Rhizophagus fasciculatus*).

Total number of nematodes were highest (2575 nematodes per 250 g soil) in T_9 (Absolute control), and it was on par with T_8 (Organic POP of KAU, 2017). Total number of nematodes were lowest (506.67 nematodes per 250 g soil) in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) followed by T_1 (*Rhizophagus fasciculatus*) with 531.00 nematodes per 250 g soil and T_4 (*Acaulospora* sp.) with 559.00 nematodes per 250 g soil.

4.8 pH AND NUTRIENT STATUS OF THE SOIL (AT HARVEST)

Initial and final nutrient status of the different treatment plots are showed in the Table 25.

Soil of the experimental site was acidic with pH of 4.6. At harvest of crop, pH reduced in every treatment plots. The lowest soil pH (3.5) was recorded in T_1 (*Rhizophagus fasciculatus*) treated plots. However, T_9 (Absolute control) and T_8 (Organic POP of KAU, 2017) had highest soil pH (4.2 and 4.1 respectively) at the time of harvest.

Table 24: Effect of different treatments on nematode population (per 250 g soil) at harvest

Treatments	Plant parasitic nematode	Saprophytic nematode	Total nematodes
T_1(*Rhizophagus fasciculatus*)	510.00^{d}	21.00^{f}	531.00^{d}
T_2 (*Funneliformis mosseae*)	1146.67^{b}	33.67^{cd}	1180.00^{b}
T_3 (*Glomus etunicatum*)	1063.67^{b}	32.67^{de}	1096.00^{b}
T_4 (*Acaulospora* sp.)	537.67^{d}	21.67^{ef}	559.00^{d}
T_5 (*Gigaspora* sp.)	766.00^{c}	44.67^{bc}	810.67^{c}
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	480.67^{d}	26.00^{def}	506.67^{d}
T_7 (POP recommendations of KAU, 2016)	809.00^{c}	49.67^{b}	858.67^{c}
T_8 (Organic POP of KAU, 2017)	2439.67^{a}	78.00^{a}	2517.33^{a}
T_9 (Absolute control)	2501.67^{a}	73.67^{a}	2575.00^{a}
Initial	2423	20	2443
CD(0.05)	145.46	11.44	145.37

Electrical conductivity in different treatments were same as initial EC (0.03 dS m^{-1}). EC of T_8 (Organic POP of KAU, 2017) reduced to 0.02 dS m^{-1}. But T_1 (*Rhizophagus fasciculatus*) and T_9 (Absolute control) showed a rise in soil EC (0.04 dS m^{-1}).

The per cent organic carbon of the soil at the time of planting was 1.46 (medium) After the experiment, the organic carbon content of soil in T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_3 (*Glomus etunicatum*), T_7 (POP recommendations of KAU, 2016) and T_8 (Organic POP of KAU, 2017) increased compared to initial status. The organic carbon content of absolute control plots were reduced to 0.96%.

Available nitrogen content in soil was low (213 kg ha^{-1}) at the start of the experiment. But it increased to medium level in every treatment at the time of harvest. Highest available soil N content (319.87 kg ha^{-1}) was in T_3 (*Glomus etunicatum*), followed by T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and T_7 (POP recommendations of KAU, 2016).

Available phosphorus content in the soil was high (34.29 kg ha^{-1}) at the time of planting and it decreased in every treatment plots after harvest. At 150 DAP, highest soil available P (36.9 kg ha^{-1}) was recorded in T_7 (POP recommendations of KAU, 2016) and lowest (17.0 kg ha^{-1}) was recorded in T_4 (*Acaulospora* sp.).

At the time of planting, soil available potassium was at medium level (181.33 kg ha^{-1}). But, the plots which treated with T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.), T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and T_7 (POP recommendations of KAU, 2016) had increased available potassium than initial status. Among the treatment, T_4 (*Acaulospora* sp.) had highest (234.08 kg ha^{-1}) available K and absolute control had the lowest (134.38 kg ha^{-1}).

Table 25: pH and nutrient status of soil in different treatments at harvest (150 DAP)

Treatments	pH	EC (dS m^{-1})	Organic Carbon (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1(*Rhizophagus fasciculatus*)	3.5	0.04	1.65	288.51	34.6	173.94
T_2 (*Funneliformis mosseae*)	3.7	0.03	1.60	301.06	34.6	211.79
T_3 (*Glomus etunicatum*)	3.8	0.03	1.52	319.87	22.9	144.82
T_4 (*Acaulospora* sp.)	3.7	0.03	1.44	288.51	17.0	234.08
T_5 (*Gigaspora* sp.)	3.9	0.03	1.44	288.51	22.3	172.82
T_6 (T_1 +T_2 +T_3 +T_4 +T_5)	3.7	0.03	1.44	307.33	23.4	183.79
T_7 (POP recommendations of KAU, 2016)	3.7	0.03	1.53	307.33	36.9	230.83
T_8 (Organic POP of KAU, 2017)	4.1	0.02	1.59	288.51	22.3	163.52
T_9 (Absolute control)	4.2	0.04	0.96	275.97	29.3	134.38
Initial	4.6	0.03	1.46	213	34.29	181.33

4.9 CORRELATION STUDIES

4.9.1 Correlation among the arbuscular mycorrhizal characters

Correlation among different arbuscular mycorrhizal characters such as per cent root colonization, AMF spore count and AMF spore diversity are given in Table 26.

Per cent root colonization was positively correlated with total AMF spores in the soil (0.567).However, AMF spore diversity showed positive correlation with per cent root colonization (0.355) and total AMF spore count (0.630).

4.9.2 Correlation between soil microclimatic parameters and soil pH with arbuscular mycorrhizal characters

Correlation between soil temperature, per cent soil moisture and soil pH with different arbuscular mycorrhizal characters such as per cent root colonization, total AMF spore count and AMF spore diversity are presented in Table 27.

Per cent root colonization by AMF in Chinese potato plants showed significant and positive correlation with soil temperature (0.545). However, soil moisture and soil pH did not have significant influence on per cent root colonization.

Total AMF spore count had a significant and positive correlation with soil temperature (0.361). But, soil moisture and soil pH were not significantly influenced total AMF spore count.

Diversity of AMF spore in the soil recorded a significant but negative correlation with soil pH (-0.297). However, soil temperature and pH did not show any significant effect.

Table 26: Correlation among the arbuscular mycorrhizal characters

AMF characters	Per cent root colonization	Total AMF spore count
Per cent root colonization	-	0.567**
Total AMF spore count	0.567**	-
AMF Spore diversity	0.355*	0.630**

*- Significant at 5% level **- Significant at 1% level

Table 27: Correlation of soil microclimatic parameters and soil pH on per cent root colonization, total AMF spore count and spore diversity

AMF characters	Per cent root colonization	Total AMF spore count	AMF Spore diversity
Soil temperature	0.545**	0.361*	0.122
Soil moisture	-0.201	0.227	-0.258
Soil pH	-0.308	0.175	-0.297*

*- Significant at 5% level **- Significant at 1% level

4.9.3 Correlation of arbuscular mycorrhizal characters and soil microbial activities

Correlation of different arbuscular mycorrhizal characters such as per cent root colonization, total AMF spore count and AMF spore diversity with dehydrogenase activity, CO_2 evolution and acid phosphatase activity are presented in Table 28.

Significant positive correlation was observed between per cent root colonization and different soil microbial activities like dehydrogenase activity (0.373), soil respiration (0.669) and acid phosphatase activity (0.648).

Total AMF spore count in the soil exhibited significant positive correlation with dehydrogenase activity (0.535) and soil respiration (0.354), however, no significant interaction with acid phosphatase activity.

AMF spore diversity recorded a significant positive correlation with soil respiration (0.580) and acid phosphatase activity (0.576). Dehydrogenase activity was not correlated with AMF spore diversity.

4.9.4 Correlation of AMF characters with biometric characters, tuber yield and P uptake in Chinese potato plant

Correlation between different arbuscular mycorrhizal characters such as per cent root colonization, total AMF spore count and AMF spore diversity with biometric characters, yield and P uptake in Chinese potato plant are depicted in Table 29.

Per cent root colonization had significant positive influence on plant height (0.684), root biomass (0.683), dry weight of plant (0.702), yield (0.388) and P uptake in plant (0.615).

AMF spore abundance in the soil showed a positive correlation with yield of the plant (0.529). The plant biometric characters and P uptake were not influenced by AMF spore abundance.

Spore diversity of AMF was not influenced any of the plant biometric characters, yield and P uptake in Chinese potato plants.

Table 28: Correlation of per cent root colonization, total AMF spore count and AMF spore diversity with soil microbial activities

AMF characters	Per cent root colonization	Total AMF spore count	AMF Spore diversity
Dehydrogenase activity	0.373*	0.535**	0.161
CO_2 evolution	0.669**	0.354*	0.580**
Acid phosphatase activity	0.648**	0.296	0.576**

*- Significant at 5% level **- Significant at 1% level

Table 29: Correlation of AMF characters with biometric characters, tuber yield and P uptake in Chinese potato plant

AMF characters	Plant height	Root biomass	Dry weight of plant	Tuber yield	P uptake in plant
Per cent root colonization	0.684**	0.683**	0.702**	0.388*	0.615**
Total AMF spore count	0.230	0.190	0.261	0.529**	0.280
AMF Spore diversity	0.077	0.010	0.27	0.148	0.282

*- Significant at 5% level **- Significant at 1% level

4.9.5 Correlation of soil microclimatic parameters and soil pH with soil microbial activities

Correlation of soil temperature, soil moisture and soil pH with dehydrogenase activity, CO_2 evolution and acid phosphatase activity are given in Table 30.

Dehydrogenase activity was not affected by soil temperature, soil moisture and soil pH.

Carbon dioxide evolution was positively correlated (0.941) with soil temperature and negatively correlated (-0.345) with soil pH. CO_2 evolution was not affected by soil moisture.

Acid phosphatase activity was positively correlated with soil temperature (0.951) and it was not affected by soil moisture and soil pH.

4.9.6 Correlation of soil microbial activities with biometric characters, yield and P uptake in Chinese potato plant

Correlation of soil microbial activities such as dehydrogenase activity, CO_2 evolution and acid phosphatase activity with biometric characters, yield and P uptake in Chinese potato plants are presented in Table 31.

Dehydrogenase enzyme activity was not significantly correlated with any of the plant biometric characters and P uptake (Table 31), but showed a significant positive correlation with tuber yield (0.647).

Plant biometric characters and P uptake were significantly and positive correlated with soil respiration and acid phosphatase activity. However, tuber yield was not influenced by them.

Table 30: Correlation of soil microclimatic parameters and soil pH with soil microbial activities

Parameters	Dehydrogenase activity	CO_2 evolution	Acid phosphatase activity
Soil temperature	-0.105	0.941**	0.951**
Soil moisture	-0.041	0.075	-0.051
Soil pH	0.055	-0.345*	-0.326

*- Significant at 5% level **- Significant at 1% level

Table 31: Correlation of soil microbial activities with biometric characters, yield and P uptake in Chinese potato plant

Soil microbial activities	Plant height	Root biomass	Dry weight of plant	Tuber yield	P uptake in plant
Dehydrogenase activity	0.126	0.067	-0.030	0.647**	-0.048
CO_2 evolution	0.668**	0.679**	0.859**	0.134	0.826**
Acid phosphatase activity	0.703**	0.656**	0.884**	0.083	0.835**

*- Significant at 5% level **- Significant at 1% level

4.9.7 Correlation of soil microclimatic parameters and soil pH with biometric characters, tuber yield and P uptake in Chinese potato plant

Correlation between soil temperature, soil moisture percent and soil pH with different plant biometric parameters, tuber yield and plant P uptake are furnished in the Table 32.

Soil temperature had significant positive correlation with plant height (0.520), root biomass (0.502), plant dry matter (0.754) and P uptake (0.714). Tuber yield was not influenced by soil temperature.

Soil moisture percent showed a significant negative influence on plant height (-0.431) and root biomass (-0.343). There was no significant correlation observed between percent soil moisture and dry matter of plant, tuber yield and plant P uptake.

Soil pH found negatively correlated with plant height (-0.691), root biomass (- 0.699), dry matter of plant (-0.581) and plant P uptake (-0.597).

Table 32: Correlation of soil microclimatic parameters and soil pH with biometric characters, yield and P uptake in Chinese potato plant

Parameters	Plant height	Root biomass	Dry weight of plant	Tuber yield	P uptake in plant
Soil temperature	0.520**	0.502**	0.754**	-.011	0.714**
Soil moisture	-0.431**	-0.343*	-0.288	0.011	-0.141
Soil pH	-0.691**	-0.699**	-0.581**	-0.234	-0.597**

*- Significant at 5% level **- Significant at 1% level

Discussion

4. DISCUSSION

Arbuscular mycorrizal fungi (AMF) are soil fungi belonging to phylum Glomeromycota, which forms symbiotic association with roots of higher plants. AMF is dependent upon host plant for fixed carbon and act as an obligate symbiont. Mycorrhizae modify the microbial ecosystem and plays an important role in growth and development of host plant. More than 80% of arbuscular mycorrhizal fungi form symbiotic association with vascular plants (Smith and Read, 2008). Since mycorrhiza are obligate symbiont, they cannot survive without a host. *Solenostemon rotundifolius* or Chinese potato is one of the important minor tuber crop rich in nutrients, cultivated in south India. Chinese potato exhibited 70- 90% of mycorrhizal dependency (Potty, 1990b).

Soil characteristics, plant properties and climatic condition are the important factors that shapes the soil microbial ecosystem and their activities (Lorgio *et al*., 1999). However, soil physico- chemical parameters and other soil properties are influenced by changes in climate. The diversity, distribution and activity of AMF and other soil microorganisms are determined by soil parameters such as soil temperature, soil moisture, soil pH and nutrient availability (Entry *et al*., 2002; Anand *et al*., 2003).

The present study was conducted to assess the impact of soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi (AMF) and to evaluate the effect of AMF on growth and yield of *Solenostemon rotundifolius* under field condition. The results obtained during the experiment are discussed in this chapter.

Arbuscular mycorrhizal fungi penetrate to the root cortex of host plant and forms network of hyphae, which helps in exchange of nutrients between the fungal and host component. Root colonization is an important parameter

which indicates the nutrient mobilization and water uptake based on the extent of root colonization. In the present study, highest root colonization (93.33%) was recorded T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) (Fig.2). Plants treated with T_2 (*Funneliformis mosseae*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) were superior in root colonization throughout the experiment. Similar results were also reported by Kennedy *et al*. (2001), where the percent root colonization by *G. mosseae* was higher than the colonization by *G. fasciculatum, Acaulospora longula, G. geosporum, G. claroideum* and *A. laevis* in papaya. Saritha *et al*. (2014) reported that combined inoculation of *Glomus* sp. (*G. mosseae, G. intraradices* and *G. fasciculatum*) increased the root colonization of sapota plants by 11- 21%. The mixed AMF application showed better per cent root colonization (86.8%) than individual inoculum (70.3%) and uninoculated control (28.6%). The better performance of consortium might be due to the multiple functional efficiency of the AMF. Among the mycorrhiza inoculated treatments, root colonization was lowest in T_5 (*Gigaspora* sp.) and T_3 (*Glomus etunicatum*) (Fig.2). Schenck and Smith (1982) reported that, optimum temperature for root colonization by *Gigaspora pellucida* and *Gigaspora gregaria* were 30^0C and for *Gigaspora gregaria* it was 36^0C. However, the temperature ranged from 25.94- 28.85^{0}C in the present study, which might have affected AMF colonization.

There was an increase in the root colonization by AMF with increase in the age of the plant except at 60 DAP (Fig.2). Potty, (1982) also reported that, root colonization increased with age of Chinese potato and 80- 85% root colonization was noted at 75- 95 DAP. According to Yaseen *et al.* (2016), association of AMF on different medicinal plants were highest during fruiting phase, compared to vegetative and flowering phases, which is in agreement with the present study. In the present study, root colonization was 80- 90% in AMF inoculated treatments. However, 66- 73% root colonization was also recorded in control which might be due due to the presence of high

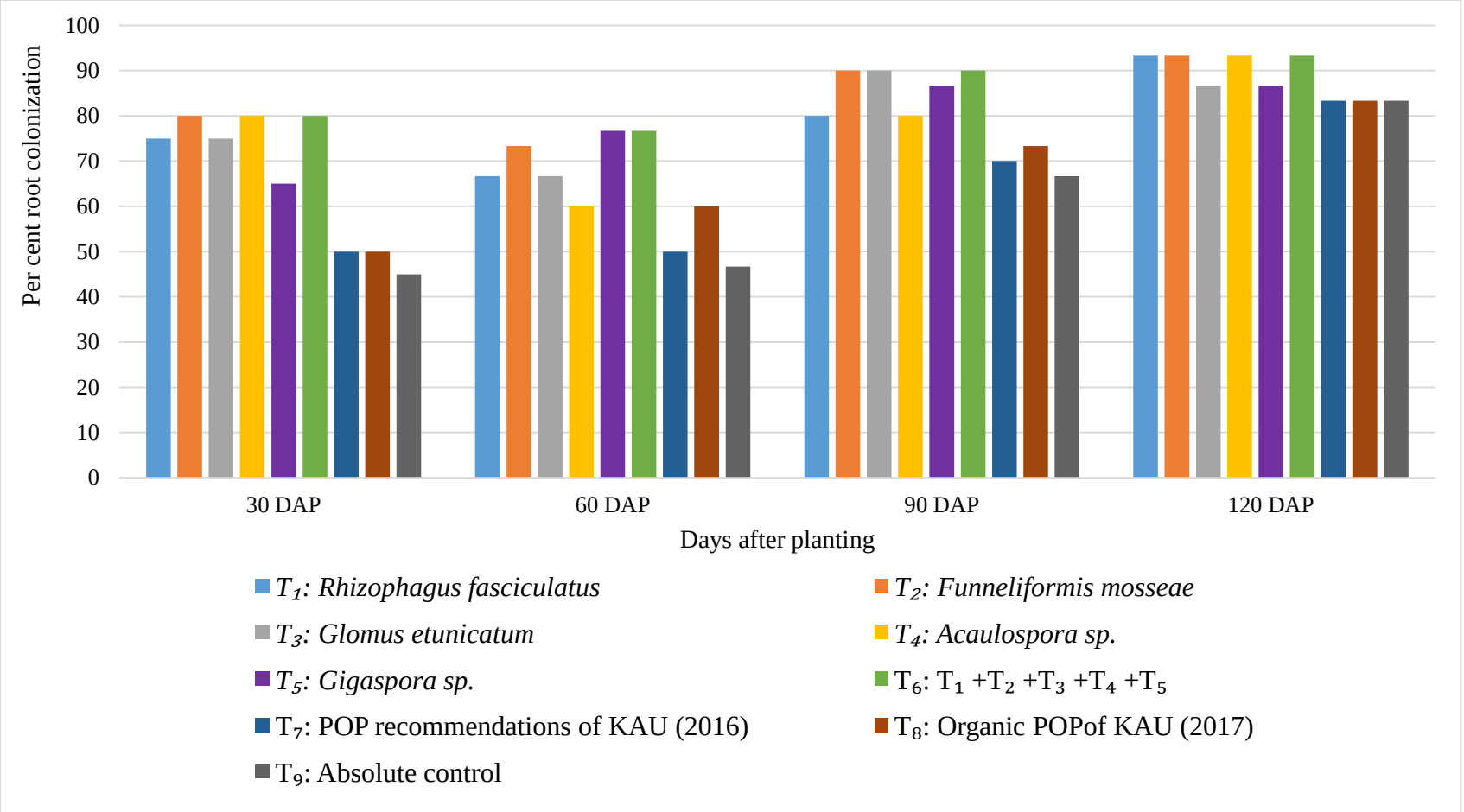


Fig. 2. Per cent AMF root colonization in Chinese potato at monthly interval

native population of AMF in the experimental soil.

Root colonization decreased at 60 DAP, except in T_8 (Organic POP of KAU, 2017) (Fig.2). It could be due to the effect of weeding, earthing up and fertilizer application carried out at 45^{th} day in the present study as per the POP recommendation (KAU). Felenou *et al*. (2017) reported that, the undisturbed soil had a higher root colonization rate as compared to disturbed soils. Onguene *et al*. (2000) and Kabir (2005) also reported similar results where they found that, mycorrhizae are concentrated in the upper soil layers and the soil disturbing activities like tillage affected persistence of them. The agricultural practices break the hyphae and inner contents get diluted. In T_8 (Organic POP of KAU, 2017), addition of PGPR mix I at 45 DAP might have helped AMF root colonization. Inoculation of PGPR increased VAM fungi root colonization by 7-23% (Meyer and Linderman, 1986).

The correlation studies in the present experiment showed a significant and positive correlation (0.567) between root colonization and AMF spore density (Table 26). The result was in line with the reports of Khakpour and Khara (2012) and Hashem *et al*. (2019), where the per cent root colonization and AMF spore count were reported to be positive and significantly correlated (0.73). But, contradictory result were also reported by Bhardwaj and Chandra (2018), where the root colonization showed negative correlation with spore count. However, positive correlation might be due to different soil edaphic factors of experimental site in the present study.

Per cent root colonization were significant and positive correlated (0.355) with AMF spore diversity (Table 26). Host specificity of AMF are not thoroughly understood (Anderson, 1988). But, the host plant genome variation decides the colonization (Lackie *et al*., 1988). Mycorrhizal colonization depends on host, plant, fungal type and environment. When the AMF diversity increases, the probability of host- fungal association also enhances.

Soil temperature showed a significant positively correlation with per cent root colonization (Table 27). Similar results were also reported by Rillig *et al*. (2002), where the hyphal length of AMF in soil enhanced by 40% in warmed treatment. The per cent root colonization also increased with soil temperature. The contradictory results were also reported by Felenou *et al*. (2017) and Bhardwaj and Chandra, (2018), where they found a negative correlation between soil temperature and root colonization. However, according to Schenck and Smith (1982), optimum temperature for AMF root colonization were depends on the species of AMF. *Glomus claroideum, Glomus datum, Gigaspora pellucida, Gigaspora gregaria* and *Acaulospora laevis* showed maximum root colonization and sporulation at 30^0C. Maximum root colonization for *Gigaspora gregaria* and *Glomus mosseae* were observed at 36^0C and 24^0C respectively. In the present study, the AMF species might have colonized well due to high temperature.

Soil pH of the experimental site became more acidic to the end of cropping season, which might be due to the root exudation of organic acid and decomposition of organic matter. Soil pH did not show a significant impact on root colonization (Table 27), even though the soil was highly acidic. It might be due to the native AMF isolated from acidic soil, which are well adapted to acidic condition used as mother culture. Sylvia and Williams, (1992) also reported that most of the AM fungi get adapted to the soil pH from which they were isolated, which is in agreement with the present study. Felenou *et al*. (2017) also reported that, pH of the study sites did not have any significant impact on root colonization and mycorrhizal symbiosis. However, pH could have an impact on the viability of the spores and not on mycorrhizal symbiosis (Wang *et al*., 2008). In the present study, percent root colonization in different treatments ranged from 83.33% to 93.33% which indicated that AMF performed well under acidic condition due to its adaptability. Sreekumar (2000) also reported that per cent root colonization of AMF in Chinese potato was higher (60-80%) in acidic soil

than alkaline soil (12- 36%).

Arbuscules and vesicles were not observed during the experiment. It might be due to very low pH. Clark and Zeto (1996) reported that arbuscular/ vesicular colonization by *Glomus etunicatum* and *G. intraradices* were less than 1% when the soil pH was 4.2-4.5, but, at the same time hyphal colonization was 27-53%. These results are in agreement with the present studies, where only hyphal colonization were observed. It was also reported that the frequency of AMF in soil was low in P rich soil (Duke *et al*., 1994), which could have affected arbuscule and vesicle formation.

The viability of AMF propagules and spore production are highly dependent on different biotic and abiotic factors. AMF spore density considered as an important parameter that depict the AMF population of soil. In the present study, at 150 DAP, spore count was highest in T_4 (*Acaulospora* sp.) treated plot followed by T_2 (*Funneliformis mosseae*) and T_6 (T_1+T_2+T_3+T_4+T_5) (Fig.3), which indicated that *Acaulospora* sp. were more adapted to acidic soil (Abbott and Robson, 1991). Among the AMF treated plots, T_3 (*Glomus etunicatum*) and T_5 (*Gigaspora* sp.) showed lowest AMF spores (Fig.3). In the earlier studies, it was reported that, spores of *Gigaspora* and *Scutellospora* took more time to develop and mature. *Gigaspora* sp. produced extensive mycelium and produced lesser number of spores as compared to *Acaulospora* sp. and *Glomus* sp. (Hepper, 1984; Piotrowski *et al*., 2004). Ambili *et al*. (2012) also reported that AMF of *Glomeraceae* and *Acaulosporaceae* were abundant in the coconut and arecanut cropping system in Kasaragod and Thiruvananthapuram districts of Kerala, where the soil were acidic.

In the present study, AMF spore count increased with increase in soil temperature (Table 27). Which is in agreement with earlier results of Bhardwaj and Chandra (2018), where a significant and positive correlation were reported between AMF spore count and temperature (r^2= 0.1468 –

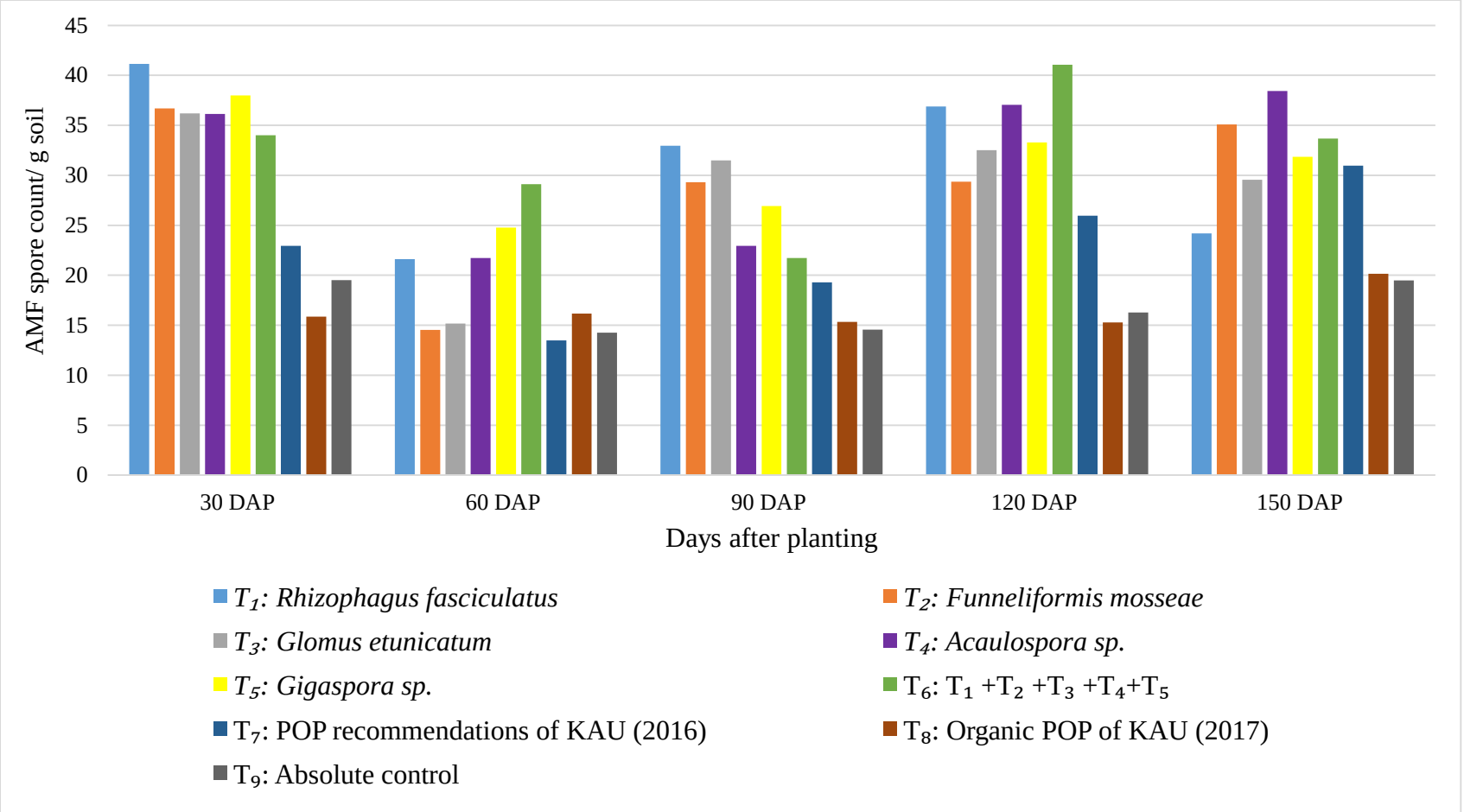


Fig. 3. Population of AMF in the rhizosphere soil of Chinese potato at monthly interval

0.2326) and recorded highest AMF sporulation (134.34 spores/ 100 g soil) during summer and lowest (58.93 spores/ 100 g soil) during spring season.

At 30 DAP, spore count of T_1 (*Rhizophagus fasciculatus*) was highest (41.13 spores/ g soil). The spore count of *Rhizophagus fasciculatus* (mother inoculum) were higher (63 spores/ g of inoculum) than other cultures (50- 59 spores/ g of inoculum), which might have increased the spore count in T_1. There was a reduction in AMF spore abundance at 60 DAP as compared to 30 DAP, except in T_8 (Organic POP of KAU, 2017). Verzeaux *et al*. (2017) also reported that AMF spore count were two-fold higher in no-till or undisturbed soil condition, which is in agreement with the present studies. Spore count was positively correlated to root colonization in the present study. The reduction in AMF spore count was higher in fertilizer treated plots, which could be due to the deleterious effect of addition of phosphatic or nitrate fertilizers on AMF life cycle. Consortium treatment (T_6) recorded highest spore abundance (29.11 spores/ g soil) at 60 DAP. Presence of different types of AMF species and their synergistic effect might have increased the spore count of T_6 compared to other treatments under disturbed soil conditions. Lowest (13.48 spores/ g soil) was in T_7 (POP recommendations of KAU, 2016). Addition N and P fertilizers might have reduced AMF spore count in T_7 at 60 DAP (Verzeaux *et al*., 2017).

In the present study, soil pH did not significantly affect total AMF spore count (Table 27), which might be due to the adaptation of AMF spores to acidic pH (3.5 to 4.6) as reported by Sylvia and Williams, (1992).

Diversity of AMF were different in each treatment and also in each month (Fig.4). Since the diversity of AMF are altered by several factors, the effect of different treatments on AMF spore diversity were difficult to understand. However, diversity index of T_6 (T_1+T_2+T_3+T_4+T_5) were better than other treatments throughout the experiment. It might be due to the presence of different kinds of AMF species in consortium, which were not present in other treatments. Diversity of AMF spores reduced at 60 DAP in

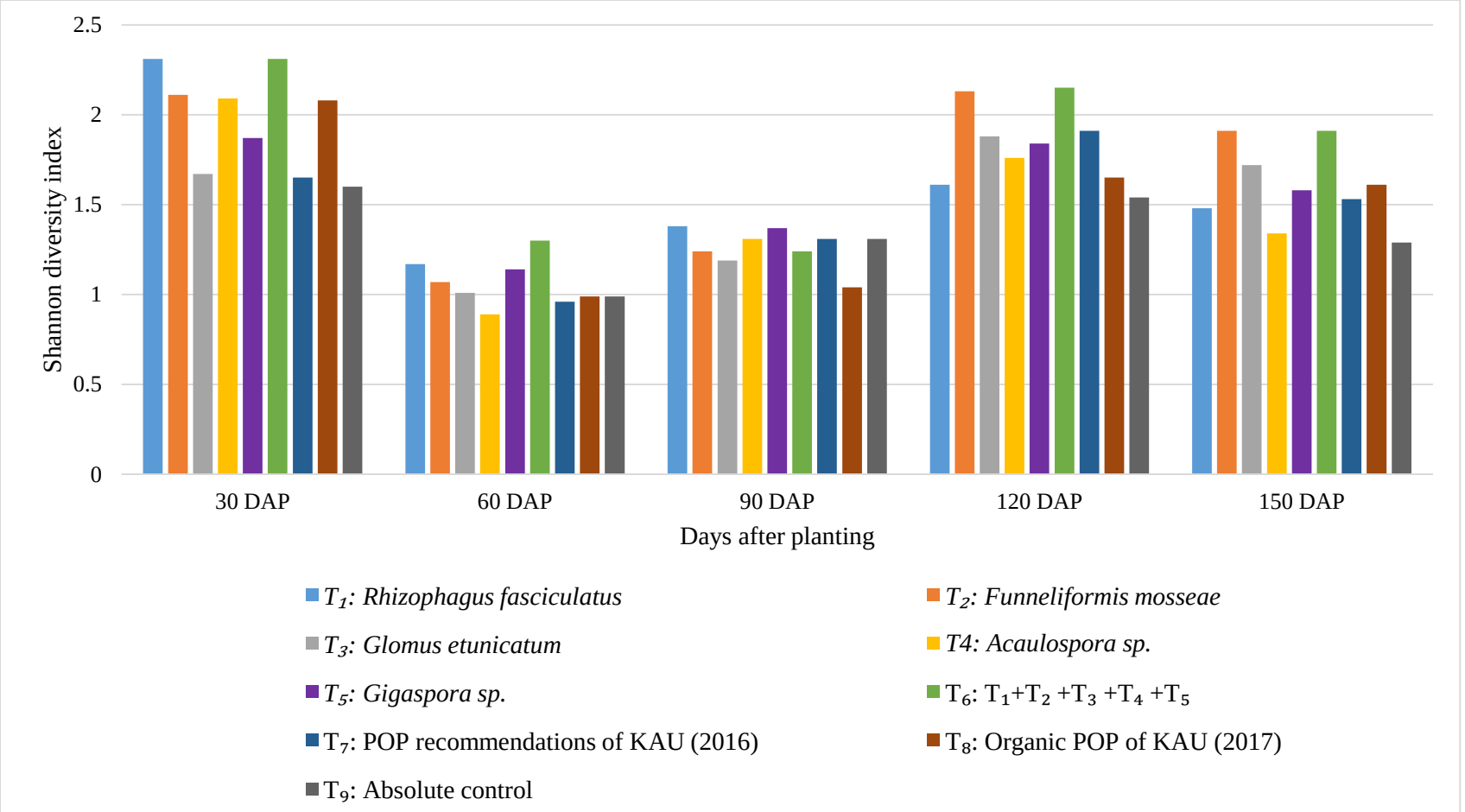


Fig. 4. AMF spore diversity in the rhizosphere soil of Chinese potato at monthly interval

all the treatments, which could be due to the higher rate of spore mortality, due to the impact of heavy rain and subsequent water saturated condition in soil during August, 2018 (Appendix I). Wangiyana *et al*. (2016) reported an increased AMF spore mortality under flooded and water saturated conditions, which is in agreement with the present study.

In the present study, soil temperature and soil moisture did not show any significant influence on AMF spore diversity (Table 27). The variation in the soil temperature and moisture were not enough to change the diversity. There was a reduction in AMF spore diversity at 60 DAP (Fig. 4), the water saturated condition of soil might have affected spores in the soil.

Soil dehydrogenase enzymes are one of the most effective bio indicator of soil microbial activity and soil quality. Dehydrogenase enzymes belong to oxidoreductase enzyme class helps in oxidation of soil organic matter (Zhang *et al*., 2010). In the present study, the dehydrogenase activity was estimated to determine its effect on AMF population and diversity.

Dehydrogenase activity was highest in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) followed by T_2 (*Funneliformis mosseae*) and T_4 (*Acaulospora* sp.) (Fig.5). Lower value were obtained in T_8 (Organic POP of KAU, 2017) and T_9 (Absolute control) (Fig.5). The variation in the dehydrogenase activity of these treatments might be due to the variation in AMF spore density. There was a significant positive correlation (0.495) between AMF spore count and dehydrogenase activity in the present study (Table 28). This result are in agreement with the reports of Verzeaux *et al*. (2017), where they observed a significant positive correlation (0.62) between spore density and dehydrogenase activity. Decreased spore density was exhibited in the soil with lowest dehydrogenase activity. Dehydrogenase activity also showed a positive correlation (0.373) with percent root colonization, which could be due to the enhanced soil aggregation and microbial activity in the mycorrhizae inoculated soil by the glomalin and glycoprotein production from extra radical hyphae of AMF (Wright and Upadhyaya, 1998; Sharma *et*

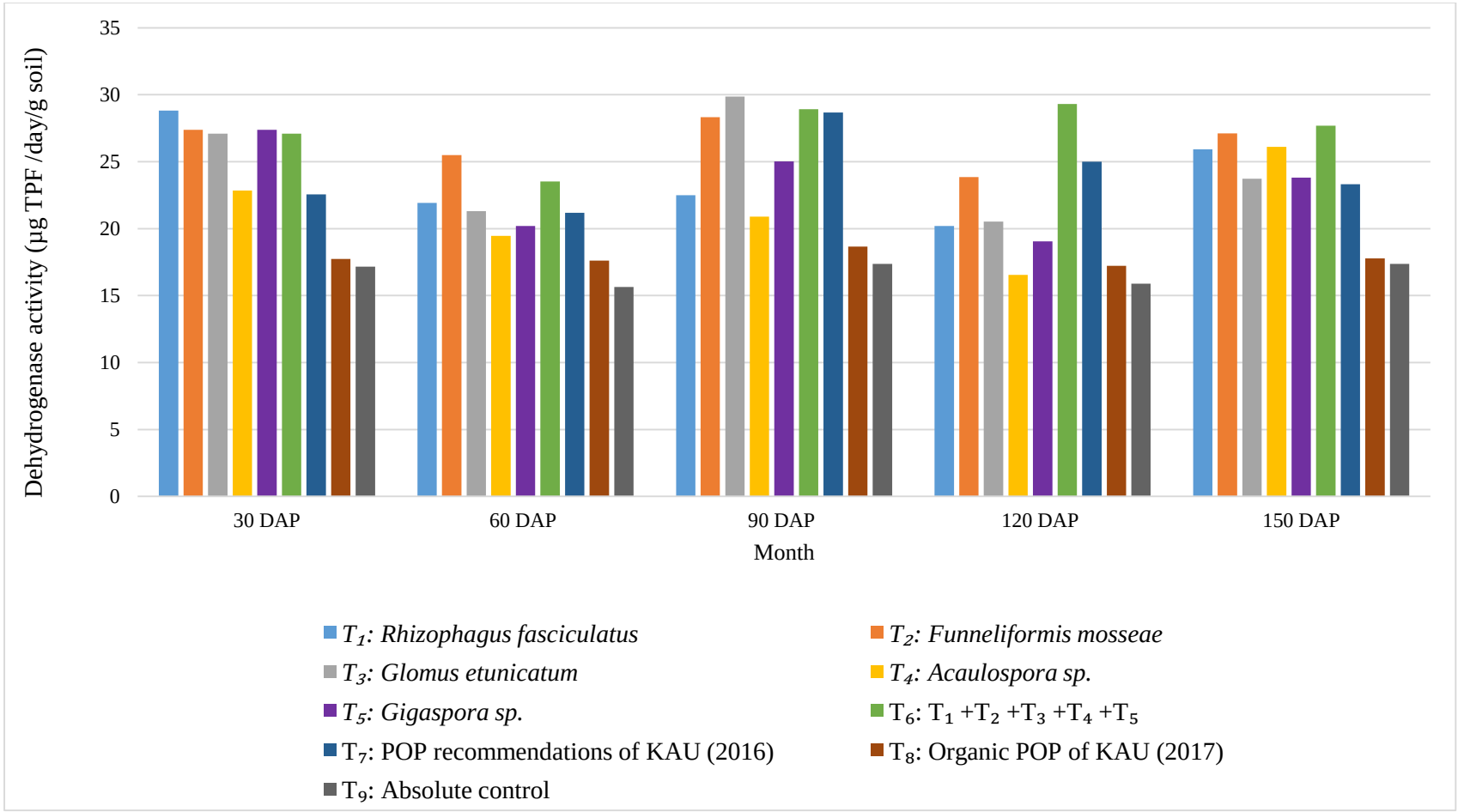


Fig. 5. Dehydrogenase activity in rhizosphere soil at monthly interval under field condition

al., 2011).

Soil respiration is the release of CO_2 from the soil due to the respiration of different soil microorganisms, plant roots, soil fauna *etc*. Soil respiration plays an important role in global carbon cycling. The rate of CO_2 evolution is highly influenced by different biotic and abiotic factors.

Carbon dioxide evolution was highest at 120 DAP, in *Gigaspora* sp. (T_5), which was on par with *Acaulospora* sp. (T_4) and *Funneliformis mosseae* (T_2). Carbon dioxide was high in AMF inoculated treatments. (Fig.6). CO_2 evolution showed a significant and positive correlation (0.669) with AMF root colonization (Table 28). The increased response of percent root colonization to CO_2 evolution might be due to the enhanced rhizospheric microbial activity or due to the increased plant growth. The plants, which were in symbiotic association with mycorrhizae provide a substantial amount of plant photosynthates to mycorrhizal component in return to other nutrients (Smith and Read, 2008). A part of plant derived carbon were transferred to soil bacteria through AM hyphae and the extra radical mycelial exudates of AM fungi improved soil bacterial growth and vitality (Toljander *et al*., 2007), which indicated that AM association enhanced the microbial activity in rhizosphere and hence the soil respiration. Higher mycorrhizal root colonization also improved total biomass production, shoot and root length, shoot and root dry matter, chlorophyll content, protein content, amino acid content and phenol content of Chinese potato plants (Sreekumar, 2000). Increased root biomass enhanced the root respiration and also soil respiration.

Carbon dioxide evolution showed a significant positive correlation (0.362) with AMF spore count (Table 28) and spore diversity. According to Wang *et al*. (2016), higher mycorrhizal infection enhanced soil respiration and sensitivity of soil respiration to temperature. AMF improved soil organic matter content and glomalin, which are associated with the carbon storage in soil.

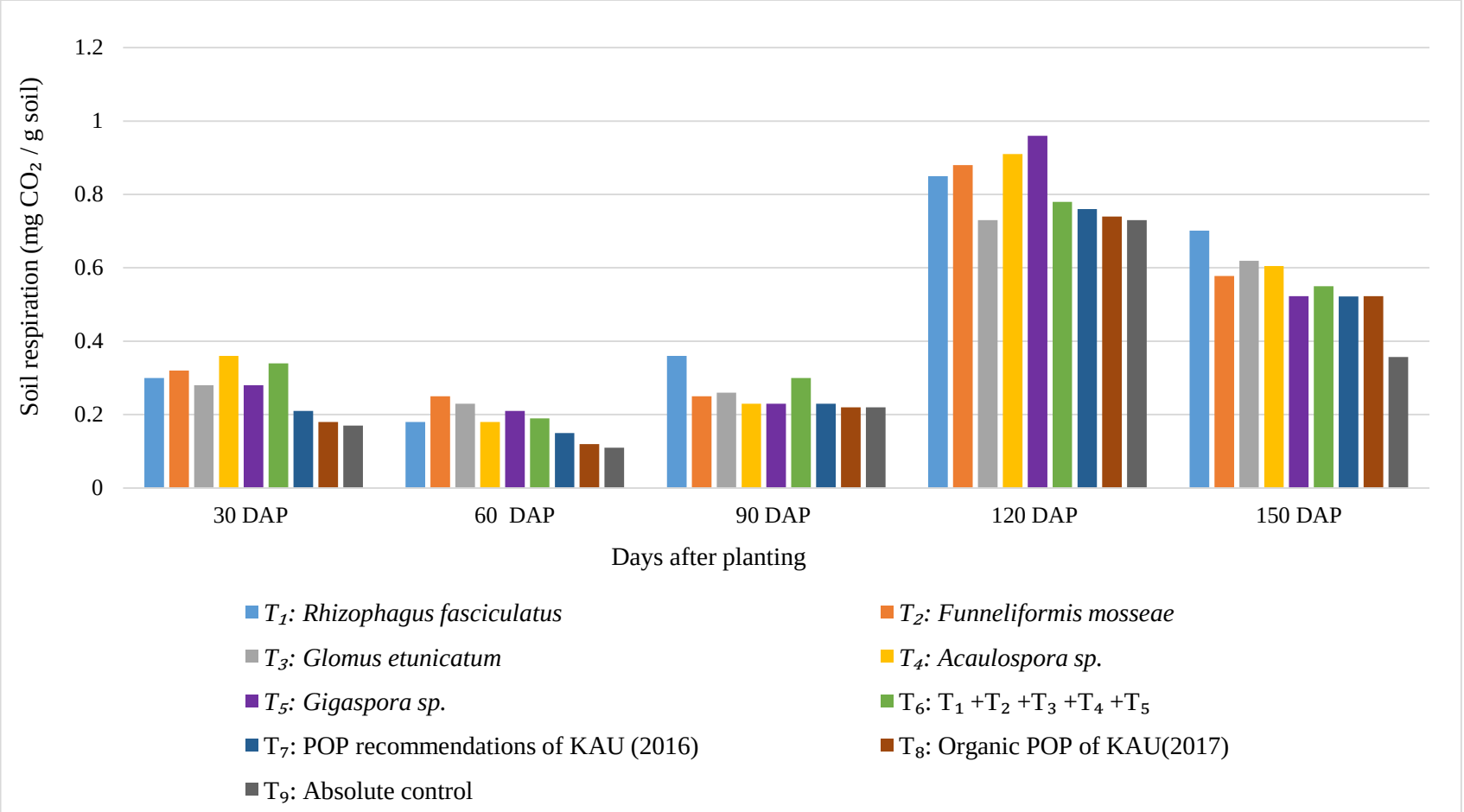


Fig. 6. Soil respiration (CO_2 evolved) at monthly interval under field conditions

Soil respiration (CO_2 evolution) increased with soil temperature, and highest soil respiration were recorded at 120 DAP, which could be due to the enhanced plant root biomass production (Wang *et al*., 2017). The major component of the soil respiration is root respiration. In farmlands, 60% of total CO_2 evolution contributed by root respiration (Rochette and Flanagan, 1996). In the present study also, soil respiration showed positive correlation with plant growth parameters such as plant height, root biomass and plant dry matter (Table 31).

There was a negative correlation between CO_2 evolution and soil pH (Table 30). CO_2 evolution might have caused acidification of soil due to the reaction with water and produced carbonic acid which is in agreement with the earlier studies of Andrews and Schlesinger (2001).

The soil respiration values were not correlating with dehydrogenase activity of soil in the present experiment, even though microorganism are involved in both these activities, which might be due to the major contribution soil respiration by crop root respiration.

Phosphatase enzyme plays a major role in phosphorus acquisition, through the hydrolysis of esters and anhydrous of phosphoric acid (Schmidt and Lawoski, 1961). The origin of phosphatase enzyme in the soil is from different biotic components such as plant roots, fungi and bacteria. The extra radical mycelium of AM fungi also release acid phosphatase and helps in the absorption of phosphorus (Sato *et al*., 2015).

In the present study, acid phosphatase activity did not differ significantly between the treatments, but it was low in control plots (Fig.7). It indicated that, acid phosphatase activity increased due to mycorrhizal inoculation and subsequent root colonization. Correlation study also showed significant positive correlation (0.648) between root colonization and acid phosphatase activity (Table 28). These result are in agreement with the reports of Priya and Kumutha (2009). AM fungal inoculation enhanced the

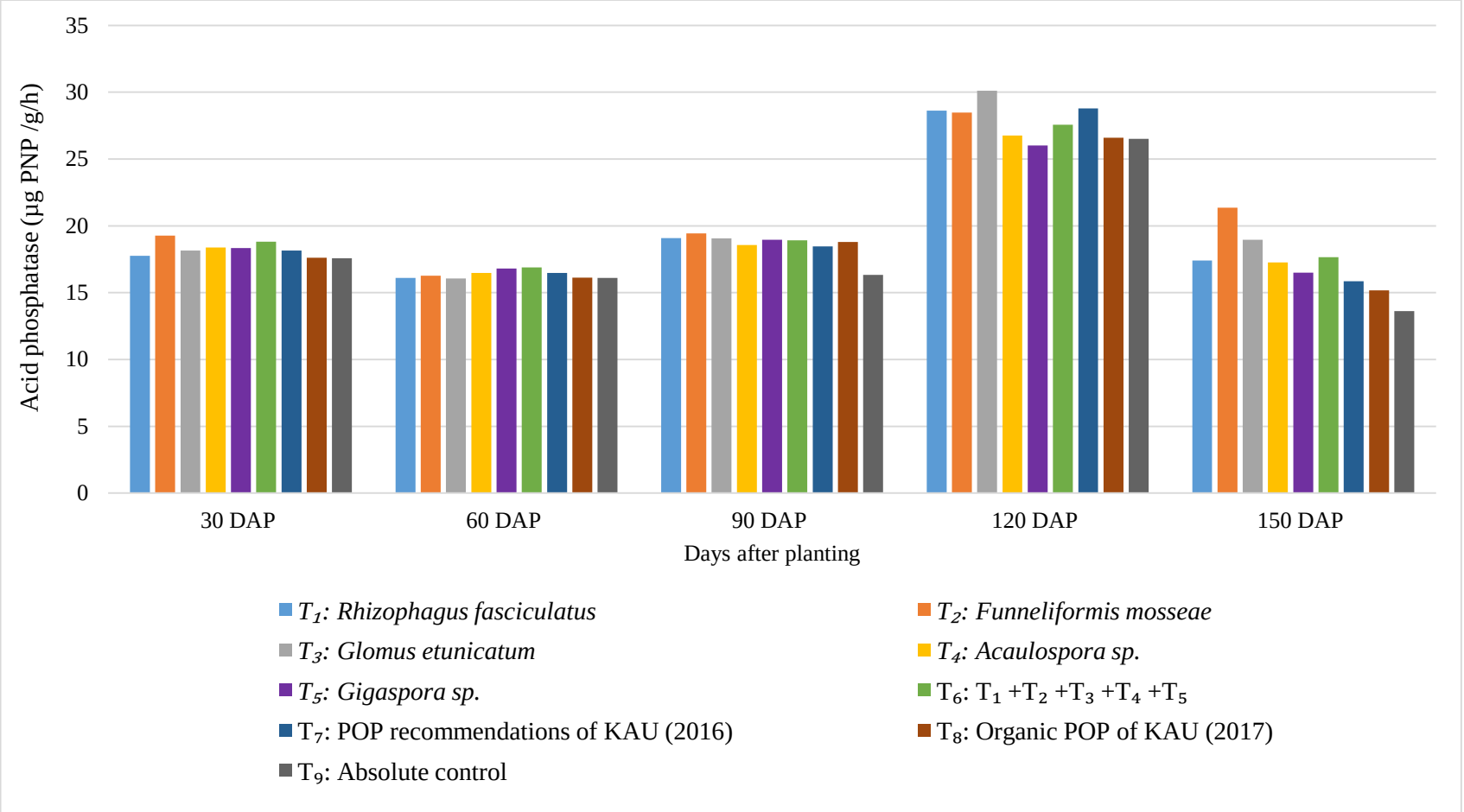


Fig. 7. Acid phosphatase activity at monthly interval under field conditions

acid phosphatase activity by 3-4 folds (46 µg) when compared to control (29.5 µg). But in present study it was 21.35 µg and 13.62 µg (Fig.9) respectively. Huang *et al*. (2009) also reported an increased acid phosphatase activity (35.8- 70.1%) in mycorrhiza applied soil compared to control. The decreased acid phosphatse activity in the present study might be due to the different soil edaphic factors and environmental conditions.

On the whole, acid phosphatase activity in T_2 (*Funneliformis mosseae*) was the highest (Fig.7). Kennedy *et al*. (2001) also reported similar findings, where acid phosphatse activity was high in *G. mosseae* compared to *G. fasciculatum*, *Acaulospora longula, G. claroideum, G, geosporum* and *A. laevis* in papaya.

Acid phosphatase activity was highest at 120 DAP, and lowest at 60 DAP (Fig.7). This might be due to the highest soil temperature at 120 DAP (28.85^0C) and lowest at 60 DAP (25.94^0C), which indicated that, the soil temperature has positively affected acid phosphatase activity. Correlation studies also showed a positive correlation (0.951) between acid phosphatase activity and soil temperature (Table 30). Studies by Kumari *et al*. (2018) showed that, soil acid phosphatase activity increased with increase in temperature from 20 to 70^0C, which is in agreement with the present study. The field evaluation of AMF is a prerequisite before confirming the efficacy of the mycorrhiza as their performance is greatly affected by biotic and abiotic factors.

A study was conducted to know the effect of AMF on biometric characters and yield of Chinese potato. Different treatments significantly influenced the plant height of Chinese potato plant. Highest plant length was observed in T_7 (POP recommendations of KAU, 2016) followed by T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_6 ($T_1 + T_2 + T_3 + T_4 + T_5$). Among the AMF treated plants, plant height was highest in T_2 (*Funneliformis mosseae*) (Fig.8). Similar observations were also reported by Tahat *et al*. (2008) in tomato plant, where *Funneliformis mosseae* performed

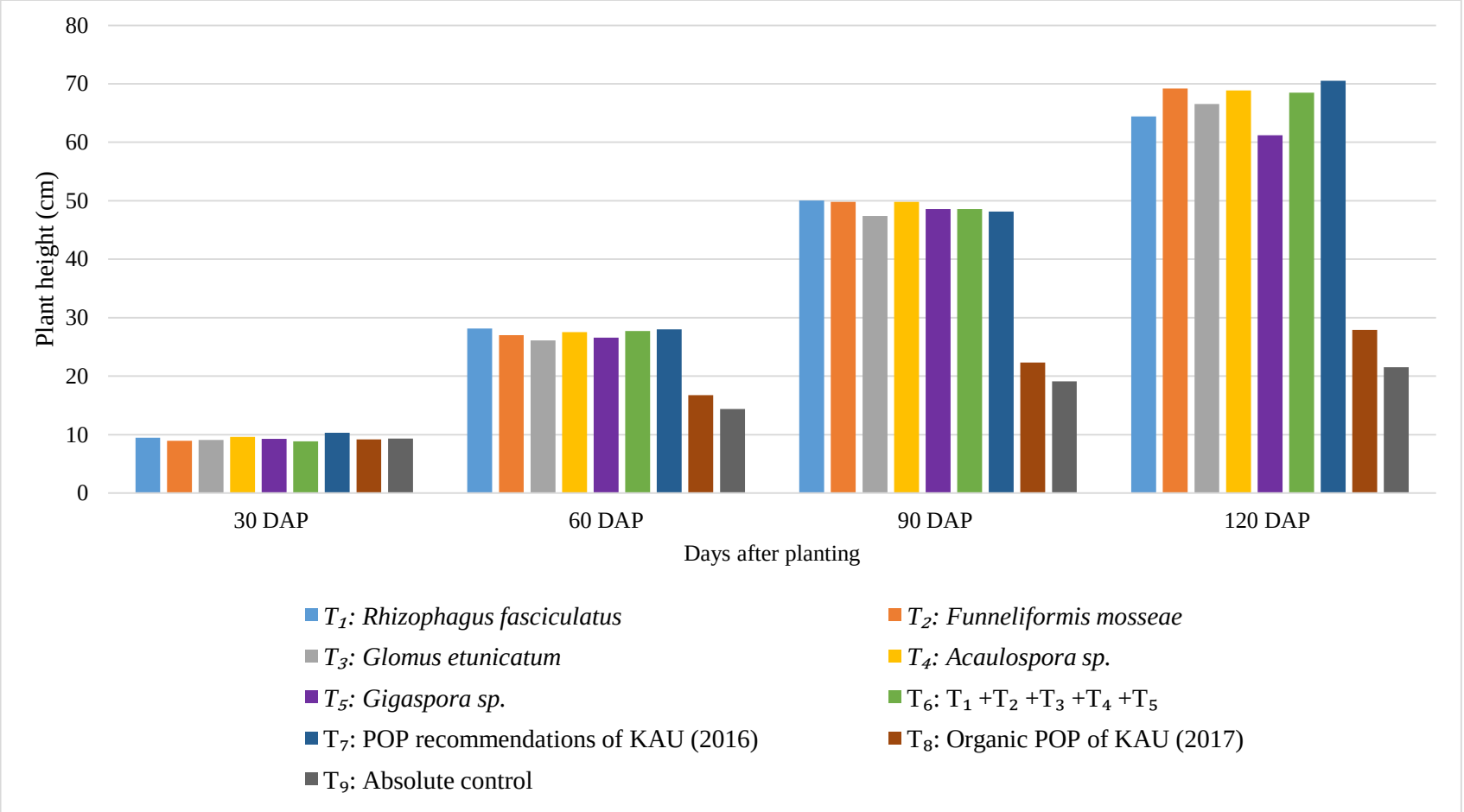


Fig. 8. Plant height of Chinese potato at monthly interval

better due to its effective and environmentally sustainable property. The highest plant height in T_7 (POP recommendations of KAU, 2016) might be due to the increased root colonization (83.33%) by native AMF that were already present in the soil. Correlation study between root colonization and plant height also supported this, which showed that root colonization enhanced the plant height of Chinese potato. Similar results were also reported by Prasad and Mertia (2005), where significant positive correlation ($r=0.906$, $p< 0.05$) were found between average tree height and per cent root colonization. Hashem *et al*. (2019) reported that, mycorrhizal root colonization showed a significant positive correlation with shoot height, number of primary and secondary branches in chick pea. According to Smith and Read (1997), AMF root colonization improved the plant growth characters due to stimulation of photosynthetic rate and increased photosynthates demand of below ground portion. The exact effect of different treatments on plant growth could be explained only under controlled condition.

In the present study, there was a positive correlation between soil temperature and plant growth parameters such as plant height, root biomass and dry matter production (Table 32) which might be due to the increased sunshine hours during that period (Appendix I), and subsequent high photosynthetic activity.

Root biomass of the plant is an important parameter that determine the absorption of nutrients and water from soil. Since the AM fungi are associated with root of the plant, the effect of different treatments on plant root biomass becomes necessary. In the present study, T_2 (*Funneliformis mosseae*) and T_4 (*Acaulospora* sp.) showed significant effect on root biomass of Chinese potato (Fig.9). Karthikeyan *et al*. (2008) reported that application of *Glomus mosseae* increased the fresh and dry weight of *Catharanthus roseus*. Kavitha and Nelson (2014) also recorded highest root biomass production in sunflower plants treated with *Funneliformis mosseae*

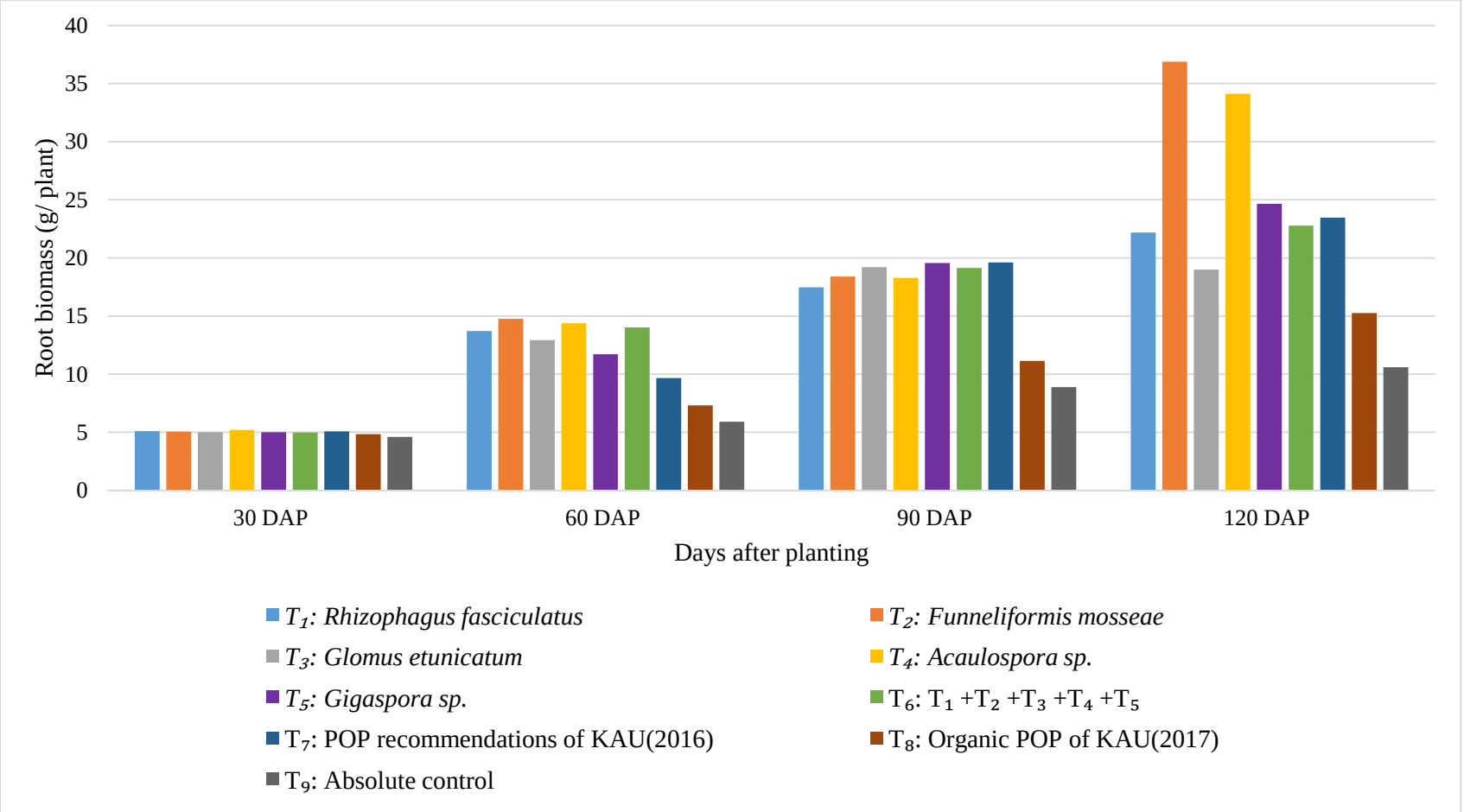


Fig. 9. Means of per plant root biomass of Chinese potato at monthly interval

than *Glomus fasciculatum* and *Acaulospora scrobiculata.* Root biomass showed a significant positive correlation (0.683) with AMF root colonization (Table 29). Similar results were also reported by Karthikeyan *et al*. (2008) and they suggested that, the enhanced root biomass of mycorrhiza inoculated plants might be due to formation of external mycelium.

Dry matter content of the plant is an important trait for understanding plant ecology, since it is related to plant growth and survival. In the present study, T_2 (*Funneliformis mosseae*) was recorded highest dry matter production (66.41 g per plant) and lowest was in the case of control plots (23.56 g per plant). Dry matter content of the mycorrhizal inoculated plants were higher than non-inoculated ones (Fig.10). Mustafa e*t al*. (2010) also reported an increased plant dry matter content in *Glomus mosseae* inoculated plants. Shoot and root dry matter contents were enhanced by 7.1- 27.5% and 9.7-75.8% respectively in *Glomus mosseae* inoculated plants over control. Mycorrhizae inoculated plants were more efficient in terms of dry matter production than the non-mycorrhizal plants (Eulenstein *et al.,* 2017), which is in agreement with the present studies.

Different treatments significantly influenced the tuber yield of Chinese potato (Fig.11). Tuber yield was highest in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) and was on par with the T_7 (POP recommendations of KAU, 2016) and T_2 (*Funneliformis mosseae*). Among the AMF treated plants, highest tuber yield was reported in T_6 (T_1+T_2+T_3+T_4+T_5) and T_2 (*Funneliformis mosseae*). However, lowest was in T_3 (*Glomus etunicatum*). Similar results were also reported by Oyetunji and Afolayan (2007) in yam, where *Glomus mosseae* enhanced the tuber yield of yam over *Glomus etunicatum.* However, the AMF treated plants were performed better than control, which indicated AMF colonization increased tuber yield of yam and it was in agreement with the present study also. Tuber yield was positively correlated (0.388) with per cent root colonization (Table 29) in the present study. The highest tuber yield in consortium might be due to synergistic effect of different AMF species

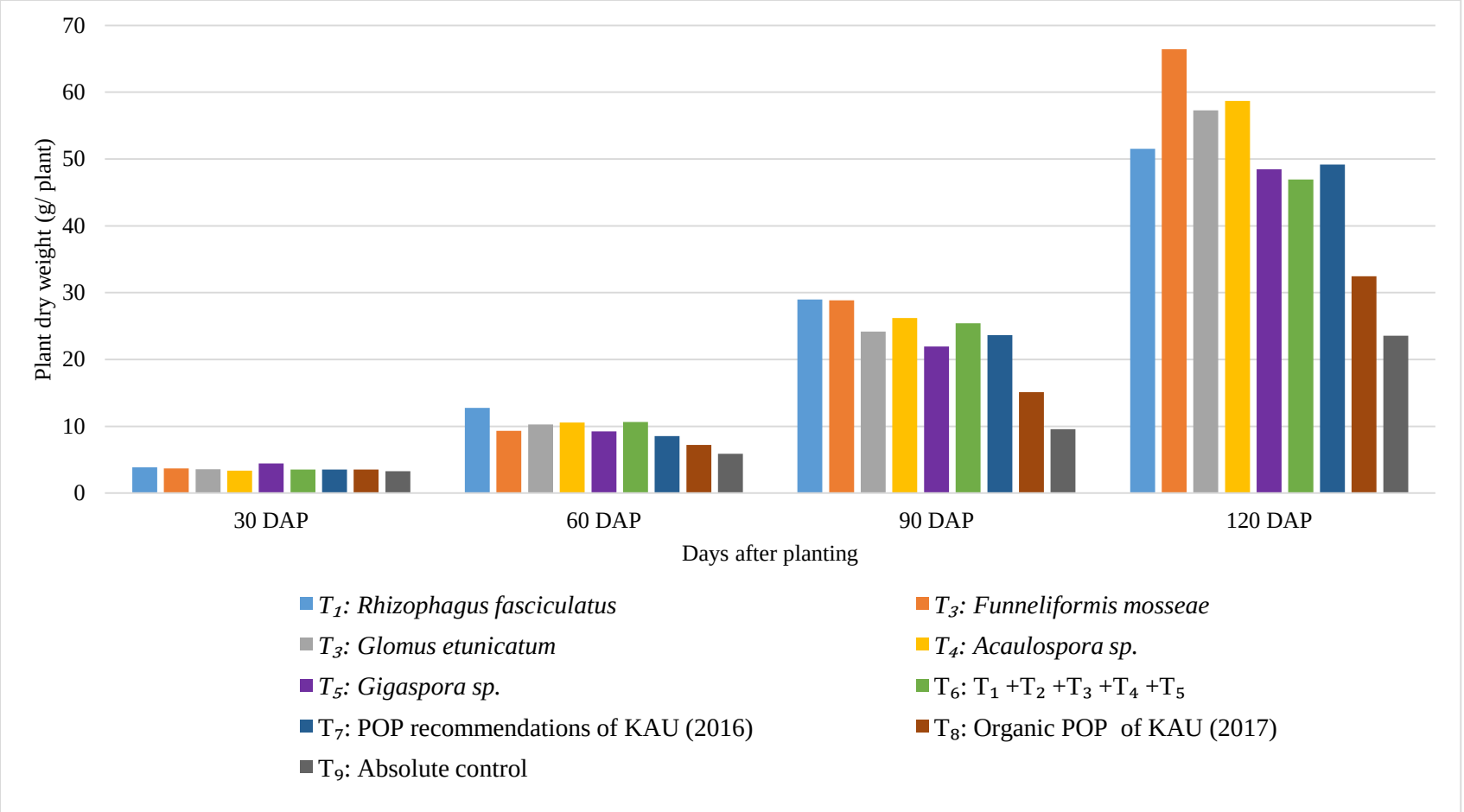


Fig. 10. Dry weight of Chinese potato plants at monthly interval

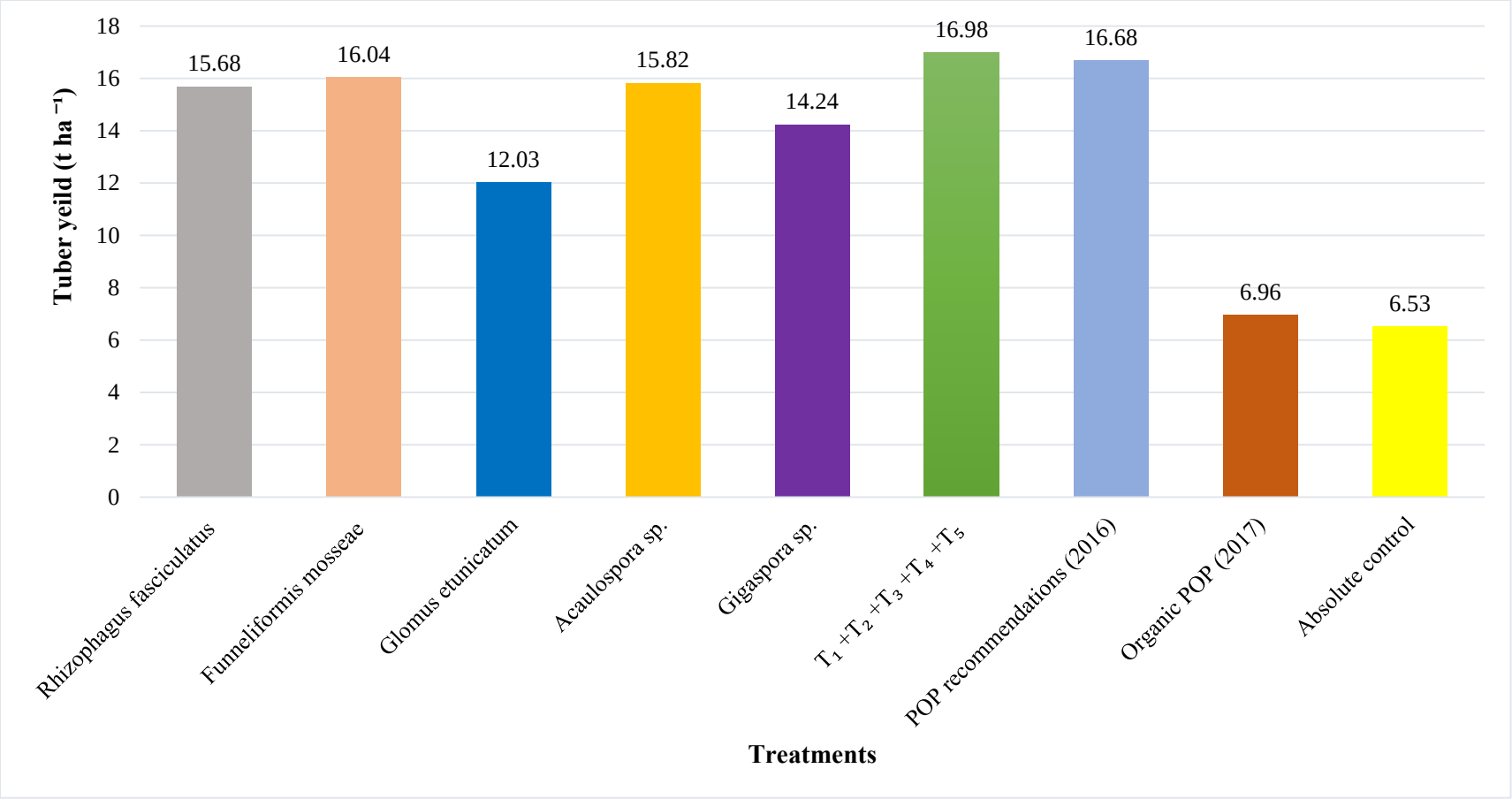


Fig. 11. Effect of different treatments on tuber yield (t ha^{-1}) of Chinese potato

and enhanced root colonization (Saritha *et al*., 2014). The tuber yield in T_7 (POP recommendations of KAU, 2016) was also on par with T_6 (T_1 +T_2 +T_3 +T_4 +T_5), which might be due to the increased root colonization (83.33%) by native mycorrhizal community in the soil.

Mycorrhizae are associated with mobilization of soil nutrients, especially phosphorus. Study of the phosphorus uptake in Chinese potato plants due to colonization by AMF will determine the efficiency of different AMF species on phosphorus mobilization. When the phosphorus uptake in Chinese potato plants were analyzed, highest P uptake were obtained in T_2 (*Funneliformis mosseae*) (Fig.12). Mustafa *et al*. (2010) also reported an enhanced P content in the tissue of sweet corn inoculated with *Glomus mosseae.* According to Chen *et al*. (2017) *Glomus mossae* enhanced root and shoot biomass and phosphorus uptake. The concentration of P in the shoot and root increased by 62.5% and 138.9% respectively.

Phosphorus uptake in plants increased with per cent root colonization (Table 29). The results are in agreement with the reports of Hashem *et al*. (2019), where the AMF inoculation and root colonization enhanced the uptake of phosphorus in chick pea plants by 21.90% compared to control plants.

In the present study, phosphorus uptake increased with increase in acid phosphatase activity (Table 31). It might be due to the organic phosphorus compounds of the soil hydrolyzed by acid phosphatase resulting in the release of inorganic phosphorus, which enhanced the phosphorus acquisition by the plants (Tarafdar and Classen, 1988).

Phosphorus uptake increased with increase in soil temperature (Table 32), due to increased dry matter production of the plant with increase in soil temperature. Similar results were also reported by Levesue and Kecheson (1963) where they found an enhanced P uptake in alfalfa plants with the soil temperature from 10^0C to 26^0C. P uptake was negatively correlated with soil pH (Table 32), which might be due to negative correlation between plant dry

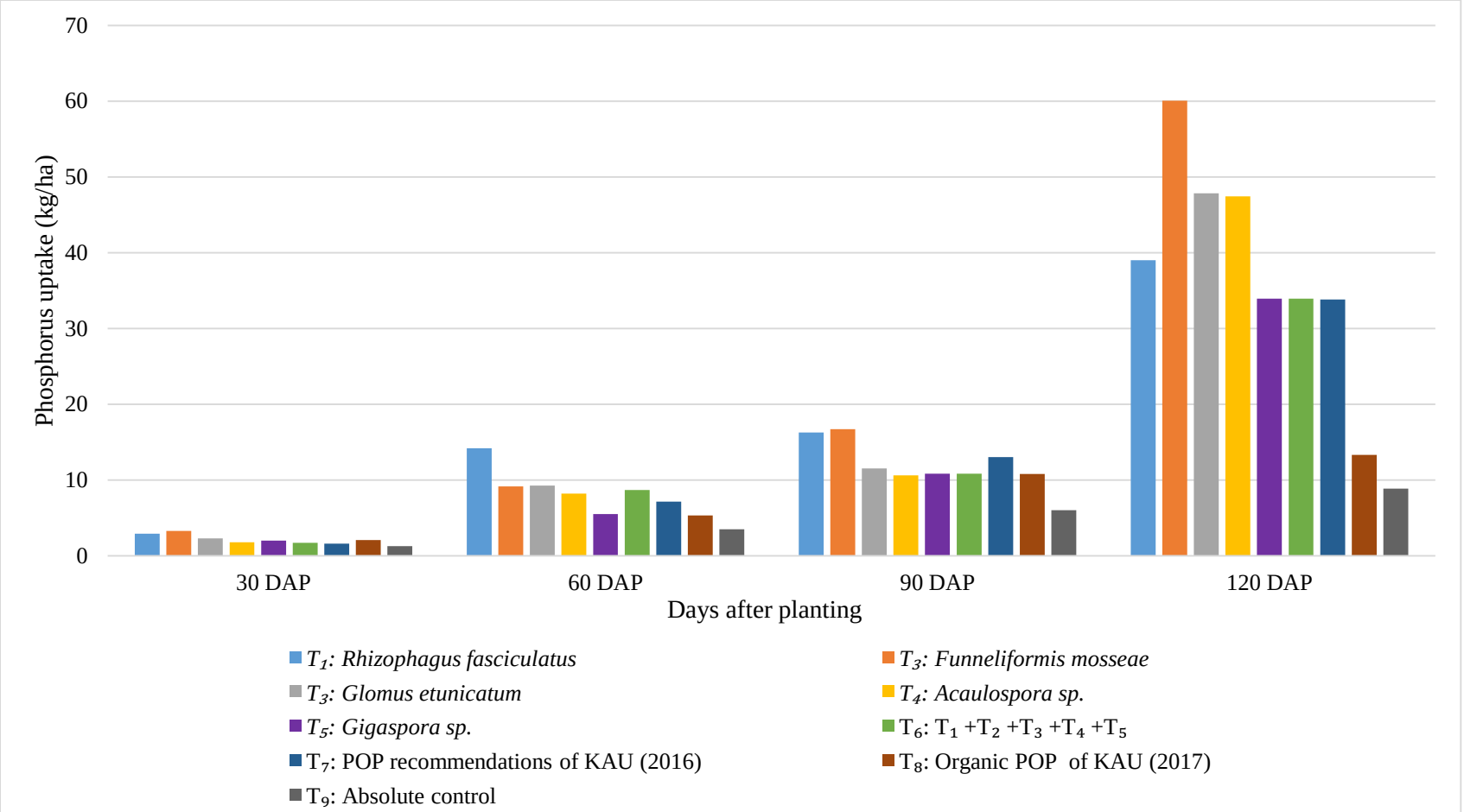


Fig. 12. Phosphorus uptake by Chinese potato plants at monthly interval

matter content and soil pH. Since, the P uptake was directly linked with the dry matter production, negatively correlation between dry matter content and soil pH also led to negative correlation between P uptake and soil pH in the present study.

Nematode infection is one of the major constraint in farming of Chinese potato. Infestation by root knot nematode on Chinese potato were reported in Kerala (Sathyrajan *et al*., 1966). In the present study, total nematode population was highest in T_9 (Absolute control), and it was on par with T_8 (Organic POP of KAU, 2017). Lowest nematode population was in the case of T_6 (T_1+T_2+T_3+T_4+T_5) followed by T_1 (*Rhizophagus fasciculatus*) and T_4 (*Acaulospora* sp.) (Fig.13). There was a significant synergistic effect on different arbuscular mycorrhiza compared to a single species inoculum observed by Ceustermans *et al*. (2018), which is in agreement with present study where consortium (T_6) had lowest nematode population. The capability of *Rhizophagus fasciculatus* to control nematode was reported by Krishna Prasad (1991). *Acaulospora colombiana* and *A. appendicular* as single or dual inoculant significantly reduced nematode egg and population densities in cassava (Sery *et al*. (2016). In absolute control (T_9) and organic POP, 2017 (T_8) had lowest mycorrhizal population (Fig.3), which might be the reason for ineffective nematode control.

Soil organic carbon content of the absolute control (T_9) were lowest (0.96%) as compared to other treatments (Table 25), since manures were not incorporated in it. Kale *et al*. (1992) reported an increased soil organic carbon percent in FYM applied treatments, which is in agreement with the present studies.

Soil available nitrogen content of all the treatments were high at the time of harvest as compared to initial status (Table 25), which might be due to the inefficient utilization of applied fertilizers by plant or by the enhanced activity of soil microflora which convert unavailable nitrogen to available form. Mycorrhizal inoculation might have also helped to increase available

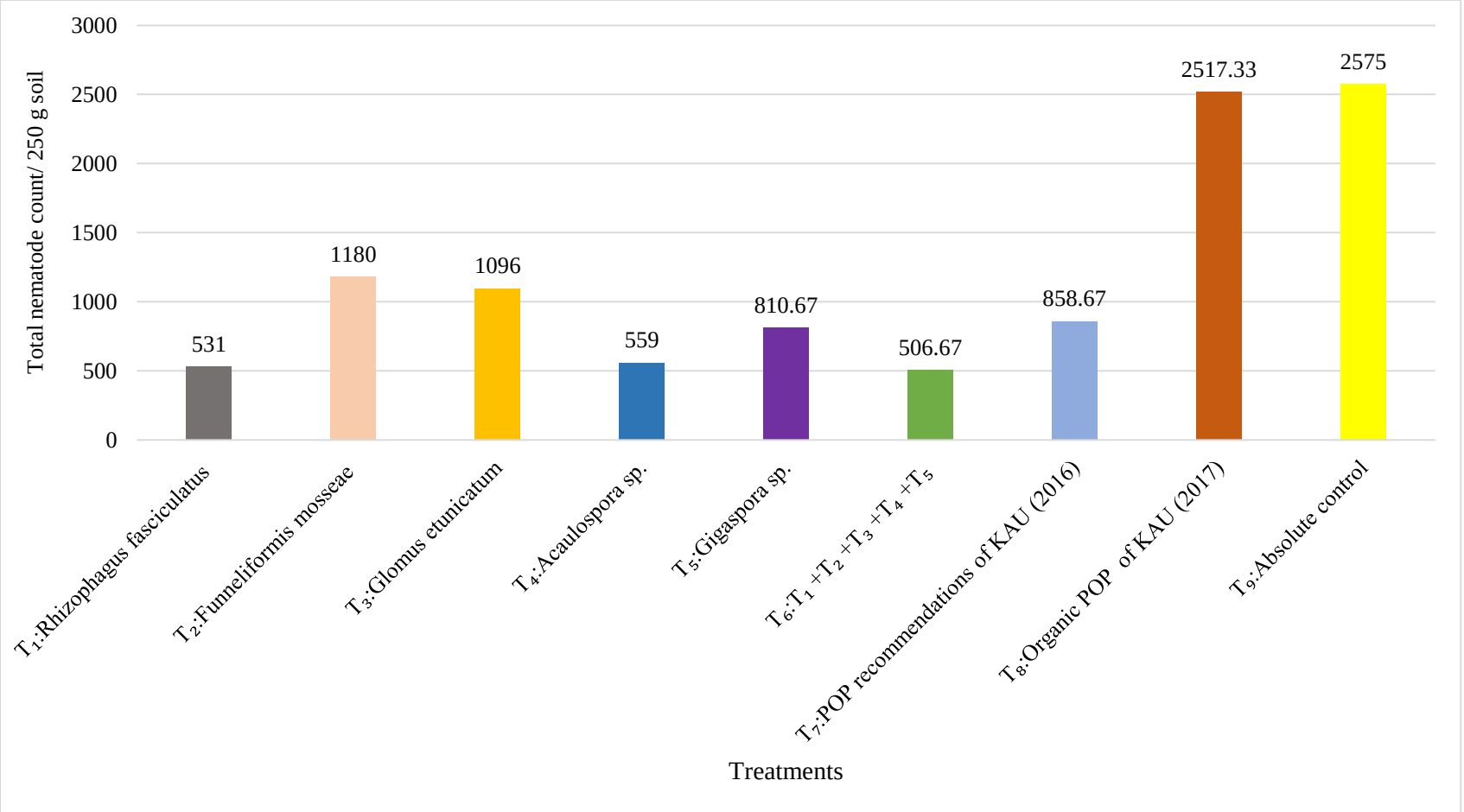


Fig. 13. Total nematode population (250 g soil) in the rhizosphere soil of Chinese potato at harvest

nitrogen content. Feng *et al*. (2002) reported an increase in amount of soil available nitrogen with mycorrhizal colonization.

The present study indicated that soil temperature affected AMF root colonization and spore count. Even though the soil pH was very low, it did not affect per cent root colonization. Soil pH showed a negative correlation with AMF spore diversity. Dehydrogenase activity, CO_2 evolution and acid phosphatase activity exhibited a positive correlation with AMF. Considering plant biometric characters, tuber yield and phosphorus uptake in Chinese potato, T_2 (*Funneliformis mosseae*) performed better than other treatments. However, extensive field trials in different seasons and agro ecological zones, are necessary to confirm it.

Future line of work

- Field evaluation of AMF under different agroclimatic zone and under different seasons.
- Identification of the AMF spores diversity through molecular techniques.
- Development of an abiotic stress tolerant culture of AMF

Summary

5. SUMMARY

The research work entitled "Soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi" was carried out in the Department of Agricultural Microbiology, College of Horticulture, Vellanikkara during 2017-2019. The objectives of the study were to determine the effect of soil microclimatic parameters and microbial activities on the population and diversity of arbuscular mycorrhizal fungi, and to evaluate the effect of AMF on the growth and yield of Chinese potato (*Solenostemon rotundifolius*). The field experiment was conducted in the Agronomy farm, College of Horticulture, Vellanikkara. 'Nidhi' variety of Chinese potato was used as host crop for AMF in the study. The treatments consisted of five different AMF species *viz., Rhizophagus fasciculatus, Funneliformis mosseae, Glomus etunicatum, Acaulospora* sp., *Gigaspora* sp., consortium of these five AMF species, POP recommendations of KAU (2016), Organic POP of KAU (2017) and absolute control. The cultures of AMF were obtained from Department of Agricultural Microbiology, COA, Vellayani, KAU. The cultivation practice explained in POP Recommendation of KAU (2016) was followed in all mycorrhiza inoculated treatments and T_7. The important findings of the study are summarized in this chapter.

Per cent root colonization of AMF on Chinese potato plants were significantly influenced by different treatments. Root colonization ranged from 45.0% to 93.33% during the entire season. Highest root colonization was observed at tuber development stage and lowest was at 60 DAP. Among the treatments, higher root colonization (93.33%) was observed in *Rhizophagus fasciculatus* (T_1), *Funneliformis mosseae* (T_2), *Acaulospora* sp. (T_4) and T_6 ($T_1 + T_2 + T_3 + T_4 + T_5$). However, lowest was in absolute control plants. Root colonization by AMF were positively correlated with AMF spore count, spore diversity and soil temperature. Soil pH did not exhibit any

significant influence on per cent root colonization. However, arbuscules and vesicles were absent in the colonized roots. Soil microbial activities like dehydrogenase activity, CO_2 evolution and acid phosphatase activity were positively correlated with AMF root colonization.

Different treatments significantly influenced the total AMF spore count in the soil. AMF spore population varied between months. Spore abundance was reduced at 60 DAP as compared to 30 DAP, except in T_8 (Organic POP of KAU, 2017). Among different treatments, T_6 (T_1 +T_2 +T_3 +T_4 +T_5) recorded highest spore abundance at 60 DAP and 120 DAP with 29.11 and 41.06 spores/ g soil respectively. But, T_4 (*Acaulospora* sp.) had highest total spore count at 150 DAP (38.44 spores/ g soil). Absolute control treatments exhibited lowest spore count during the experiment. Total AMF spore count of the soil showed a positive correlation with per cent root colonization and spore diversity. Spore count increased with increase in soil temperature, but not affected by soil moisture and soil pH. Dehydrogenase activity and CO_2 evolution showed a positive correlation with total spore count.

Highest AMF spore diversity was recorded in T_1 (*Rhizophagus fasciculatus*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) at 30 DAP with Shannon diversity index 2.31. Among the treatments T_6 (T_1 +T_2 +T_3 +T_4 +T_5) was with highest AMF spore diversity throughout the experiment. AMF spore diversity showed positive correlation between per cent root colonization and AMF spore count. Soil pH negatively influenced the AMF spore diversity.

Mean monthly soil temperature was highest at 120 DAP, which ranged from 28.83^0C to 28.87^0C and lowest was at 60 DAP, which ranged from 25.92^0C to 25.97^0C. Higher soil moisture percent was recorded in all the treatments at 30 DAP and 60 DAP. However, lowest soil moisture percent was at 90 DAP (7.13%). Soil pH was recorded highest at 30 DAP and lowest at 150 DAP. Soil became more acidic towards the time of harvest. On the

whole highest soil pH (5.07) of the experiment was recorded in T_8 (Organic POP of KAU, 2017) at 30 DAP and lowest (3.5) was in T_1 (*Rhizophagus fasciculatus*) at 150 DAP.

Dehydrogenase activity showed significant difference among the treatments. Among all the treatments T_2 (*Funneliformis mosseae*) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5) recorded highest dehydrogenase activity throughout the experiment. Dehydrogenase activity was not influenced by soil temperature, soil moisture and soil pH. Per cent root colonization and total AMF spore count were positively correlated with soil dehydrogenase activity. CO_2 evolution was highest (0.96 mg CO_2 g^{-1} soil) in T_5 (*Gigaspora* sp.) which was on par with T_4 (*Acaulospora* sp.) and T_2 (*Funneliformis mosseae*). AMF treated plots were with higher carbon dioxide evolution than other ones. CO_2 evolution increased with soil temperature, but not affected by soil moisture. Soil pH and CO_2 evolution exhibited a negative correlation. Acid phosphatase activity were higher in T_2 (*Funneliformis mosseae*) and T_3 (*Glomus etunicatum*). Soil temperature significantly increased acid phosphatase activity. But, soil moisture and soil pH did not influence acid phosphatase activity.

Plant height of Chinese potato were significantly affected by different treatments, except at 30 DAP. T_7 (POP recommendations of KAU, 2016) had highest plant length (70.53 cm) at 120 DAP and it was on par with all other mycorrhizal treatments, except T_5 (*Gigaspora* sp.).

Plant height increased with AMF root colonization and soil temperature. Soil moisture and soil pH were negatively correlated with plant height. However, plant height showed significant positive correlation on CO_2 evolution and acid phosphatase activity. Root biomass of the Chinese potato plants were significantly influenced by different treatments. During the whole experimental season, highest root biomass was observed in T_2 (*Funneliformis mosseae*) and lowest was in absolute control. Root biomass increased with AMF root colonization and soil temperature. Soil moisture

and soil pH showed negative correlation with root biomass. But, root biomass exhibited positive correlation with CO_2 evolution and acid phosphatase activity. Dry weight of the plants were significantly affected by different treatments. Among the treatments the plants treated with T_2 (*Funneliformis mosseae*) had highest dry matter content at tuber developing stage. Per cent root colonization improved dry matter content of the plant. Dry matter content of the plant were positively correlated with CO_2 evolution and acid phosphatase activity. However, dry matter content exhibited a negative correlation on soil pH. Soil temperature enhanced dry matter content of the plant. Days taken for first flowering were not significantly influenced by AMF inoculation. AMF consortium treated plants recorded highest tuber yield, which was also on par with T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_7 (POP recommendations of KAU, 2016). Tuber yield was significantly influenced by AMF root colonization and spore count. Phosphorus uptake by Chinese potato plants were significantly affected by different treatments. Highest P uptake was recorded in T_2 (*Funneliformis mosseae*) and lowest were in absolute control. P uptake in plants increased with per cent root colonization, soil temperature, CO_2 evolution and dehydrogenase activity.

Nematode population of the soil exhibited a significant differences among the treatments. Consortium of AMF were more effective in nematode control. Nematode population were lowest (506.67 nematodes per 250 g soil) in T_6 (T_1 +T_2 +T_3 +T_4 +T_5), which was on par with T_1 (*Rhizophagus fasciculatus*) and T_4 (*Acaulospora* sp.). Highest nematode count (2575 nematodes per 250 g soil) were in T_9 (Absolute control), which was on par with T_8 (Organic POP of KAU, 2017).

The present study indicated that soil temperature affected AMF root colonization and spore count. Even though the soil pH was very low, it did not affect per cent root colonization. Soil pH showed a negative correlation with AMF spore diversity. Dehydrogenase activity, CO_2 evolution and acid

phosphatase activity exhibited a positive correlation with AMF. Considering plant biometric characters, tuber yield and phosphorus uptake in Chinese potato, T_2 (*Funneliformis mosseae*) performed better than other treatments. However, extensive field trials in different seasons and agro ecological zones, are necessary to confirm it.

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Appendices

APPENDIX I

Daily weather data during the experiment at Vellanikkara, Thrissur

Date	Temperature ^{0}C				Soil temperature ^{0}C		Relative humidity (%)		Sun shine (hrs)	Rain fall (mm)	Number of rainy days
	MAX		MIN		15 cm	15 cm					
	I	II	I	II	I	II	I	II			
14/06/18	27.4	25.5	23.0	23.0	26.0	26.7	99	98	0.0	128.2	1.0
15/06/18	26.9	28.9	23.7	23.7	26.3	28.7	98	84	0.0	10.2	1.0
16/06/18	28.9	32.1	23.4	23.4	26.6	30.0	92	72	0.0	0.2	0.0
17/06/18	32.2	30.0	23.7	23.7	27.4	29.6	95	70	8.8	0.7	0.0
18/06/18	30.3	31.4	23.4	23.4	27.0	30.6	98	72	0.1	7.1	1.0
19/06/18	31.4	29.1	22.2	22.9	27.0	28.7	99	95	5.1	46.7	1.0
20/06/18	29.1	27.6	22.2	22.2	26.0	27.6	96	97	0.7	66.2	1.0
21/06/18	27.6	26.9	23.0	23.0	26.0	27.5	96	91	0.0	3.5	1.0
22/06/18	26.9	28.8	22.3	22.3	26.0	28.1	95	98	0.0	5.3	1.0
23/06/18	28.8	29.6	22.4	22.4	26.2	28.1	96	81	0.6	12.5	1.0
24/06/18	23.6	31.0	22.4	22.4	26.6	30.4	95	70	0.6	1.4	0.0
25/06/18	31.0	31.4	23.2	23.2	27.3	30.4	95	76	4.5	8.1	1.0
26/06/18	31.4	30.7	22.3	22.3	27.0	29.7	96	75	3.9	15.3	1.0
27/06/18	30.7	30.6	23.5	23.5	27.5	29.9	95	74	1.4	3.5	1.0
28/06/18	30.6	26.0	21.9	21.9	27.0	27.9	98	92	0.0	40.4	1.0
29/06/18	26.0	29.0	22.3	22.3	26.2	28.9	96	95	0.0	26.0	1.0
30/06/18	29.0	31.8	21.7	21.7	26.1	31.3	91	68	0.4	4.5	1.0
01/07/18	31.8	31.8	23.4	23.4	27.6	31.1	95	70	7.9	0.2	0.0
02/07/18	31.8	32.3	23.7	23.7	27.9	32.1	97	61	7.3	0.5	0.0
03/07/18	32.3	32.1	23.2	23.2	28.0	31.2	95	67	7.4	2.2	0.0
04/07/18	32.1	32.7	22.9	22.9	27.7	32.3	90	62	5.8	0.0	0.0
05/07/18	32.7	32.1	23.4	23.4	27.9	32.6	90	57	8.7	0.0	0.0
06/07/18	32.1	30.7	21.9	21.9	27.5	31.1	96	69	7.7	9.0	0.0
07/07/18	30.7	30.5	24.3	24.3	28.1	30.6	89	83	2.7	0.2	0.0
08/07/18	30.6	29.7	21.5	21.5	26.8	28.9	98	75	0.2	53.6	1.0
09/07/18	29.7	25.0	22.5	22.4	26.8	26.9	98	95	0.0	40.2	1.0
10/07/18	25.0	28.8	22.4	22.4	25.5	28.3	99	88	0.0	49.0	1.0
11/07/18	28.8	25.6	21.5	21.5	25.1	26.3	98	97	0.0	87.8	1.0
12/07/18	25.6	30.0	21.7	21.7	24.0	28.6	98	90	0.0	48.1	1.0
13/07/18	30.0	29.5	22.2	22.2	26.0	28.7	98	75	1.1	12.1	1.0
14/07/18	29.5	30.5	22.1	22.1	26.1	29.1	96	74	0.1	32.1	1.0
15/07/18	30.5	26.7	21.3	21.3	26.3	26.9	98	93	1.1	34.9	1.0
16/07/18	26.7	27.2	20.7	20.7	25.0	26.2	98	92	0.0	95.2	1.0
17/07/18	28.9	29.9	20.4	20.4	24.8	28.4	98	93	0.0	34.6	1.0
18/07/18	29.9	28.0	20.8	20.8	24.6	27.8	98	91	0.1	70.7	1.0
19/07/18	28.0	27.1	22.5	22.5	25.5	27.5	93	95	0	15.9	1.0
20/07/18	27.1	27.6	22.1	22.1	25.3	27.4	96	89	0	26.7	1.0
21/07/18	27.6	30.0	23.4	23.4	25.7	29.0	95	75	0	12.5	1.0
22/07/18	30.0	30.1	22.7	22.7	26.1	29.6	92	75	0.2	0.5	0.0
23/07/18	30.1	29.1	22.7	22.7	26.2	29.0	93	87	0.3	14.9	1.0
24/07/18	29.1	28.1	22.3	22.3	26.0	27.1	95	82	0.6	39.2	1.0
25/07/18	28.1	28.8	22.7	22.7	25.7	27.9	97	79	0	23.6	1.0
26/07/18	28.8	29.9	23.2	23.2	26.1	29.3	96	71	0	22.7	1.0
27/07/18	29.9	30.3	22.5	22.5	26.0	29.6	96	70	0.7	1.8	0.0
28/07/18	30.3	30.1	23.4	23.4	26.5	29.7	95	75	1.9	1.9	0.0

29/07/18	30.1	30.5	23.9	23.9	26.9	30.1	98	76	2.2	6.4	1.0
30/07/18	30.5	29.9	23.8	23.8	27.3	29.6	97	84	1.5	17.3	1.0
31/07/18	29.9	26.4	23.1	23.1	26.8	26.4	98	97	0.0	41.4	1.0
01/08/18	27.8	30.6	22.7	22.7	25.5	29.4	98	74	0.0	14.3	1.0
02/08/18	30.0	31.3	23.3	23.3	26.5	30.9	98	66	3.2	3.5	1.0
03/08/18	31.4	30.3	22.7	22.7	27.0	30.6	95	69	4.7	13.1	1.0
04/08/18	30.4	29.4	23.5	23.5	27.0	28.9	95	75	1.3	0.0	0.0
05/08/18	29.8	30.2	23.0	23.0	26.5	30.3	98	75	0.0	14.0	1.0
06/08/18	30.2	30.0	23.3	23.3	26.6	28.9	93	74	1.4	0.6	0.0
07/08/18	30.0	27.5	21.7	21.7	25.0	27.4	98	87	2.2	33.6	1.0
08/08/18	28.9	27.9	21.7	21.7	24.9	26.9	98	86	0.0	110.6	1.0
09/08/18	27.9	28.6	22.3	22.3	25.5	27.3	98	81	0.0	29.5	1.0
10/08/18	28.6	29.9	22.8	22.8	25.5	28.7	95	78	0.4	6.7	1.0
11/08/18	29.9	28.3	22.0	22.0	25.8	29.7	98	92	0.0	13.5	1.0
12/08/18	28.3	27.3	21.5	21.5	29.7	27.3	96	84	0.0	14.1	1.0
13/08/18	27.3	29.9	22.3	22.3	25.5	28.5	98	80	0.3	26.5	1.0
14/08/18	27.9	26.9	22.3	22.3	26.1	26.3	96	98	0.0	8.3	1.0
15/08/18	26.9	24.0	21.9	21.9	24.6	24.3	95	98	0.0	140.6	1.0
16/08/18	24.0	25.3	21.4	21.4	23.4	24.3	96	95	0.0	253.6	1.0
17/08/18	25.3	28.8	21.0	21.0	23.0	26.2	96	93	0.0	148.4	1.0
18/08/18	28.8	27.9	21.5	21.5	24.0	26.5	97	95	0.0	23.6	1.0
19/08/18	27.9	28.9	21.3	21.3	24.5	27.5	96	72	0.0	28.0	1.0
20/08/18	28.9	29.8	22.3	22.3	25.0	27.7	98	75	3.1	2.6	1.0
21/08/18	29.8	30.5	22.5	22.5	25.1	29.3	96	74	1.6	1.7	0.0
22/08/18	30.5	30.7	22.3	22.3	25.6	29.3	90	68	7.5	7.1	1.0
23/08/18	30.7	30.9	21.9	21.9	25.8	29.2	96	68	6.7	1.5	0.0
24/08/18	30.9	31.0	22.3	22.3	26.0	30.3	95	64	5.7	0.0	0.0
25/08/18	31.0	31.0	21.8	21.8	26.0	30.4	97	65	9.3	0.0	0.0
26/08/18	31.0	30.3	21.9	21.9	26.2	29.6	95	67	6.1	0.0	0.0
27/08/18	30.3	29.1	22.5	22.5	26.4	28.3	95	82	5.6	0.0	0.0
28/08/18	29.1	29.1	22.3	22.3	26.0	28.9	95	79	0.1	9.7	1.0
29/08/18	29.1	30.1	21.2	21.2	25.5	29.1	98	70	0.2	22.4	1.0
30/08/18	30.1	30.7	22.4	22.4	26.2	29.9	93	69	2.4	0.2	0.0
31/08/18	30.7	30.5	23.5	23.5	26.8	30.3	95	72	6.6	0.3	0.0
01/09/18	30.5	31.0	23.3	23.3	27.0	30.4	97	65	1.7	0.0	0.0
02/09/18	31.0	31.0	22.9	22.9	27.0	30.6	90	67	3.4	0.0	0.0
03/09/18	31.0	31.9	23.2	23.2	26.9	32.2	92	53	5.7	0.0	0.0
04/09/18	31.9	31.0	23.0	23.0	27.4	32.1	92	65	10.1	0.0	0.0
05/09/18	31.0	31.4	22.2	22.2	27.1	32.3	95	59	9.5	0.0	0.0
06/09/18	31.4	31.0	22.3	22.3	27.4	32.3	92	62	9.3	0.0	0.0
07/09/18	31.0	31.8	21.8	21.8	27.0	32.3	90	60	7.6	0.0	0.0
08/09/18	31.8	31.8	21.9	21.9	27.3	32.3	90	57	10.0	0.5	0.0
09/09/18	31.8	32.0	21.0	21.0	27.3	34.1	95	60	10.2	0.0	0.0
10/09/18	32.0	32.4	21.7	21.7	27.8	34.0	88	51	10.3	0.0	0.0
11/09/18	32.5	31.9	21.7	21.7	28.0	34.2	90	61	10.4	0.0	0.0
12/09/18	31.9	32.3	22.7	22.7	28.6	34.5	92	60	9.2	0.0	0.0
13/09/18	32.3	31.9	22.4	22.4	28.4	34.2	90	52	8.4	0.0	0.0
14/09/18	31.9	32.1	21.6	21.6	28.2	33.5	93	57	8.3	0.0	0.0
15/09/18	32.1	32.8	22.5	22.5	28.5	34.3	83	57	7.4	0.0	0.0
16/09/18	32.8	29.3	23.1	23.1	29.0	29.9	88	75	9.4	0.0	0.0
17/09/18	29.9	32.0	23..4	23..4	27.9	33.3	96	62	0.2	0.3	0.0
18/09/18	32.0	31.9	22.5	22.5	28.2	32.7	93	60	6.6	0.0	0.0
19/09/18	31.9	31.1	23.2	23.2	28.5	32.2	95	60	5.9	0.4	0.0
20/09/18	31.5	32.9	23.1	23.1	28.4	33.2	93	47	5.3	0.2	0.0

21/09/18	33.2	32.4	21.4	21.4	27.9	33.5	92	55	8.4	0.0	0.0
22/09/18	32.4	33.4	22.0	22.0	28.5	33.7	85	53	9.2	0.0	0.0
23/09/18	33.4	33.0	22.8	22.8	29.1	33.7	93	61	9.6	0.0	0.0
24/09/18	33.1	33.0	21.8	21.8	29.0	33.5	91	65	8.4	1.5	0.0
25/09/18	33.0	33.3	21.7	21.7	27.9	33.3	95	56	3.3	1.2	0.0
26/09/18	33.3	34.4	22.9	22.9	28.3	34.3	93	58	7.2	0.0	0.0
27/09/18	34.4	34.3	23.2	23.2	28.5	34.6	90	60	8.3	0.0	0.0
28/09/18	34.3	34.4	22.5	22.5	28.9	33.5	81	65	5.3	0.0	0.0
29/09/18	34.4	32.8	22.6	22.6	27.7	30.2	95	75	5.6	24.9	1.0
30/09/18	32.8	32.8	23.4	23.4	27.0	31.3	90	64	2.0	0.0	0.0
01/10/18	32.8	34.1	20.9	20.9	26.5	32.3	96	61	3.0	32.1	1.0
02/10/18	34.3	34.3	22.3	22.3	28.1	32.7	89	56	7.4	0.0	0.0
03/10/18	34.3	33.8	20.8	20.8	27.5	32.0	96	67	4.6	4.3	1.0
04/10/18	33.8	30.4	18.0	18.0	26.9	30.3	94	73	5.3	39.9	1.0
05/10/18	30.4	32.8	23.7	23.7	26.7	31.3	83	63	0.5	2.5	1.0
06/10/18	32.8	33.0	24.6	24.6	26.5	30.6	80	63	6.5	52.2	1.0
07/10/18	33.0	34.0	25.2	25.2	26.8	31.5	83	70	4.0	0.0	0.0
08/10/18	34.0	32.3	23.8	23.8	27.1	31.7	92	78	5.7	0.0	0.0
09/10/18	32.3	30.0	22.6	22.6	26.0	29.3	96	81	3.3	52.1	1.0
10/10/18	30.0	32.1	23.3	23.3	26.4	31.4	95	71	0.4	0.0	0.0
11/10/18	32.1	33.1	24.8	24.8	27.7	31.7	93	68	8.9	0.0	0.0
12/10/18	33.1	35.4	25.0	25.0	27.8	32.1	95	66	7.3	0.3	0.0
13/10/18	35.4	32.5	25.0	25.0	28.0	31.6	97	72	7.2	0.0	0.0
14/10/18	32.5	32.0	23.6	23.6	27.4	30.7	95	64	4.2	13.3	1.0
15/10/18	32.0	31.8	23.7	23.7	27.0	30.3	97	71	3.8	1.3	0.0
16/10/18	31.8	30.4	24.5	24.5	27.5	29.8	95	91	3.0	0.0	0.0
17/10/18	30.4	31.0	22.2	22.2	26.2	30.4	96	62	1.9	31.8	1.0
18/10/18	31.0	33.2	23.7	23.7	27.2	32.0	90	58	8.3	0.0	0.0
19/10/18	33.8	31.8	22.4	22.4	27.3	30.7	98	67	8.3	51.0	1.0
20/10/18	32.7	30.9	23.0	23.0	26.9	30.3	98	69	3.2	40.8	1.0
21/10/18	30.9	32.8	22.6	22.6	26.8	30.7	98	56	2.8	21.6	1.0
22/10/18	33.1	32.3	23.8	23.8	27.6	30.6	95	85	6.2	2.8	1.0
23/10/18	32.4	33.2	21.7	21.7	26.4	30.7	95	48	3.2	37.0	1.0
24/10/18	33.6	33.1	22.2	22.2	26.6	30.5	85	48	7.8	0.0	0.0
25/10/18	33.3	33.1	23.4	23.4	27.0	28.6	92	46	9.4	0.0	0.0
26/10/18	33.3	33.1	23.2	23.4	25.4	29.7	66	47	6.0	0.0	0.0
27/10/18	33.4	33.4	22.7	23.2	25.7	30.5	67	41	9.5	0.0	0.0
28/10/18	33.4	33.4	21.8	22.7	25.7	30.4	66	26	9.1	0.0	0.0
29/10/18	33.9	33.9	21.3	21.3	25.3	26.9	83	58	9.7	0.0	0.0
30/10/18	32.9	34.3	21.8	21.8	25.9	32.3	95	46	5.7	0.0	0.0
31/10/18	34.3	33.8	23.1	23.1	26.6	32.4	90	58	9.4	0.0	0.0
01/11/18	33.8	31.0	24.1	24.1	27.6	31.3	95	57	7.0	0.0	0.0
02/11/18	31.0	31.3	24.3	24.3	26.9	31.2	78	64	3.8	0.0	0.0
03/11/18	31.4	32.3	25.3	25.3	27.0	31.6	78	63	3.1	0.0	0.0
04/11/18	32.3	33.4	23.6	23.6	26.7	31.4	75	45	4.4	1.0	0.0
05/11/18	33.6	33.9	24.3	24.3	26.9	33.1	81	48	9.5	0.0	0.0
06/11/18	33.9	32.6	23.4	23.4	27.5	32.0	77	53	9.1	0.0	0.0
07/11/18	32.7	33.9	22.3	22.3	27.0	32.0	78	45	5.8	0.0	0.0
08/11/18	33.9	33.4	22.9	22.9	27.4	31.6	79	49	6.5	0.0	0.0
09/11/18	33.8	33.5	23.4	23.4	27.6	32.8	82	57	6	0.0	0.0
10/11/18	33.5	33.8	22.6	22.6	27.5	32.8	80	45	4.3	0.0	0.0
11/11/18	33.8	33.9	21.9	21.9	27.6	32.9	82	40	9.9	0.0	0.0
12/11/18	34.0	32.5	23.3	23.3	28.0	33.6	90	55	8.6	0.0	0.0
13/11/18	32.6	33.4	22.9	22.9	28.0	32.6	95	61	7.3	0.0	0.0

14/11/18	33.4	34.1	23.0	23.0	28.0	33.3	92	48	6.6	0.0	0.0
15/11/18	34.1	34.3	21.8	21.8	27.4	33.8	88	41	8.7	0.0	0.0

APPENDIX II

Package of Practices Recommendation of KAU (2016)

- FYM @ 10 t ha^{-1} at the time of preparation of beds.
- N: P_2O_5: K_2O (30:60:50 kg ha^{-1}) may be applied as basal at the time of land preparation.
- N: K_2O (30:50 kg ha^{-1}) may be applied at 45days after planting.

APPENDIX III

Organic Package (Ad hoc) of Practices Recommendation of KAU (2017)

- FYM @10 t ha^{-1} at the time of preparation of beds.
- FYM (6 t ha^{-1}) and PGPR mix I (2.5 kg ha^{-1}) may be applied at 45days after planting.

SOIL MICROCLIMATIC PARAMETERS AND MICROBIAL ACTIVITIES ON THE POPULATION AND DIVERSITY OF ARBUSCULAR MYCORRHIZAL FUNGI

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ABSTRACT OF THE THESIS

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Abstract

Arbuscular mycorrhizal fungi (AMF) are ubiquitous, which promote the plant growth by assisting in nutrient uptake and also mitigate several biotic and abiotic stresses in plants. Soil temperature, soil moisture, soil pH and nutrient availability are the major factors that affect the diversity, distribution and activity of AMF. The arbscular mycorrhizal fungi are obligate symbiont and require a host plant to complete its life cycle. *Solenostemon rotundifolius* or Chinese potato is one of the important minor tuber crop of Kerala, which is rich in starch, proteins, vitamins and minerals, with 70- 90% mycorrhizal colonization.

The present study was undertaken to assess the effect of soil microclimatic parameters and microbial activities on the population and diversity of AMF and also evaluate the influence of AMF on the growth and yield of *Solenostemon rotundifolius*. The field experiment was conducted in a randomized complete block design (RCBD) with nine treatments and three replications at Agronomy farm, College of Horticulture, Vellanikkara during 2017 to 2019. The treatments consisted of five AMF species *viz*., *Rhizophagus fasciculatus* (T_1), *Funneliformis mosseae* (T_2), *Glomus etunicatum* (T_3), *Acaulospora* sp. (T_4), and *Gigaspora* sp. (T_5), consortium of AMF (T_6), POP recommendations of KAU, 2016 (T_7), Organic POP of KAU, 2017 (T_8) and absolute control (T_9).

Per cent AMF root colonization was higher (93.33%) in *Rhizophagus fasciculatus* (T_1), *Funneliformis mosseae* (T_2), *Acaulospora* sp. (T_4) and T_6 (T_1 +T_2 +T_3 +T_4 +T_5). Spore population varied between the months, but highest spore population were recorded at 30 DAP and 120 DAP, whereas lowest was at 60 DAP. However, AMF spore diversity was highest in T_6 (T_1 +T_2 +T_3 +T_4 +T_5) throughout the experiment.

AMF spore count and per cent root colonization increased with soil temperature but, not affected by soil moisture and soil pH. However, AMF spore diversity decreased with soil pH.

Funneliformis mosseae (T_2) and consortium of AMF (T_6) recorded highest dehydrogenase activity throughout the experiment. Carbon dioxide evolution was

highest at 120 DAP, in *Gigaspora* sp. (T_5), which was on par with *Acaulospora* sp. (T_4) and *Funneliformis mosseae* (T_2). Acid phosphatase activity was highest in *Funneliformis mosseae* (T_2) followed by *Acaulospora* sp. (T_4).

Per cent root colonization by AMF was positively correlated with dehydrogenase activity, CO_2 evolution and acid phosphatase activity. AMF spore population was positively correlated with dehydrogenase activity and CO_2 evolution. AMF spore diversity was positively correlated with CO_2 evolution and acid phosphatase activity.

Funneliformis mosseae (T_2) showed better performance with respect to biometric characters (plant height, root biomass and dry weight) of the plant. AMF consortium (T_6) treated plants recorded highest (16.98 t ha^{-1}) tuber yield, which was also on par with T_1 (*Rhizophagus fasciculatus*), T_2 (*Funneliformis mosseae*), T_4 (*Acaulospora* sp.) and T_7 (POP recommendations of KAU, 2016). Phosphorus uptake by Chinese potato plants were highest (60.06 kg ha^{-1}) in T_2 (*Funneliformis mosseae*) and lowest in absolute control. Plant biometric characters, tuber yield and P uptake in Chinese potato were enhanced with AMF root colonization.

Consortium of AMF (T_6), *Rhizophagus fasciculatus* (T_1) and *Acaulospora* sp. (T_4) treated plots were recorded with less nematode population (506.67 to 559 nematodes per 250 g soil).

The present study indicated that soil temperature affected AMF root colonization and spore count. Increase in soil microbial activities (dehydrogenase activity, CO_2 evolution and acid phosphatase activity) showed increased root colonization, spore count and spore diversity. AMF root colonization enhanced growth, phosphorus uptake and yield of plant. *Funneliformis mosseae* (T_2) was the most promising AMF for improving the growth, yield and phosphorus uptake in *Solenostemon rotundifolius.* However, extensive field studies are needed under different seasons and agro ecological zones, in order to develop an abiotic stress tolerant AMF for Chinese potato plant.