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A REVIEW ON NEMATODES AND MYCORRHIZZA ASSOCIATION AT RHIZOSPHERIC ZONE OF PADDY

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ABSTRACT

Nematode is painstaking as solemn pest of paddy, may beginning up to 90% yield losses in severe cases. The nematode-mycorrhiza association at rhizospheric zone of paddy is experimental. The present study will help to detect the plant parasitic nematodes- mycorrhiza presence of rice and status of soil ecosystem at rhizospheric zone of paddy. The control measures against the PPNs and use of mycorrhiza will be helpful to enhance the rice production of the whole world. It will ultimately be helpful to establish sustainable development procedures.

Keywords: Nematode-mycorrhiza association, Paddy, PPN, Sustainable development.

INTRODUCTION

India is the world's second-largest producer of Rice (*Oryzasativa* L.) (106.5 million Tonnes per annum), and the largest exporter of rice in the world. It is a staple food and essential source of nutrition and calories for more than 50% of world populations (FAO,2016). Processed rice not only feeds more than 60% worlds human populations but other animals and birds too(Sandhu, 2014).About 15% to our national production is contributed solely from West Bengal which is highest among the 29 states. West Bengal was also a big reservoir of rice biodiversity (Chatterjee *et al.* 2008*).* Up to 1970 more than 5000 folk rice varieties had been reported form Bengal, but now it become 200 (Bose,2020). South 24 Pargana is the medium productive area of paddy among all districts (1,500-2,000 Kg/Ha.) (Anon,2010.).

The estimated average loss due to nematodes is about 15% reaching up to 90% if infested with plant parasitic nematodes like *Aphelenchoides besseyi* (White Tip Nematode), *Ditylenchus angustus* (Stem Nematode), *Heterodera oryzae* (Cyst Nematode), *Hirschmanniella oryzae* (Rice Root Nematode), *Meloidogyne graminicola* (Root Knot Nematode) etc. (Gantait *et al.*, 2018). The plant parasitic nematodes act as casual agents of many soil-borne fungal and viral diseases in paddy. Alongside their parasitic nature, nematodes also perform a major role in control of the microbial biomass in an ecosystem. The saprophagous nematodes help in maintaining eco-balance in terrestrial fauna, while some serve as the bio-indicator of soil pollution.

Nematodes belong to the phylum Nematoda and are one of the most abundant groups in the soil and litter, having a significant role in determining the microbial communities in soil. Most of the soil nematodes are microscopic, tiny, and cannot be seen by naked eyes. Generally, they possess a cylindrical body with a few exceptions like kidney shapes or fusiform structures. They are characterized by the triploblastic, pseudocoelomate body with acoelomate digestive system, well developed reproductive and nervous system. It has been reported that 50%of total nematode population on earth belong to the marine environment, 25% are free living, 15% are animal parasitic and only 10% of the nematode population are plant parasitic (Ayoub, 1980).Apart from the percentage of abundance, nematodes can be classified based on their feeding habits i.e. herbivores or plant parasites, algal feeders, fungal feeders, unicellular eukaryotes feeders, bacterial feeders and omnivores(Yeates *et.al.*,1993).The rhizosphere is one of the most diverse and complex soil environments on earth (Mendes *et al.*, 2013; Pii *et al.*, 2015).

Mycorrhiza is the symbiotic, ubiquitous relationship between plants and fungi mainly belonging to the order Glomales (Maitra *et.al*, 2021). They are found colonizing in the rhizospheric region of almost 70 to 80% of plants across the globe. These symbiotic relationships are known to confer various effects and influences on the plants. Extensive study on the mycorrhizosphere (the zone influenced by both the root and mycorrhizzal fungus) habitat showed that the symbiotic relationship both physically and chemically impact the structure of rhizosphere, it's surrounding communities and the ecosystem. (Cavagnaro, 2008). Presence of *Arthrobotrys oligospora* (nematode trapping fungus), *Pochonia* etc in rhizosphere trap and kill nematodes. (Hsueh.et.al.2013).

Mycorrhizospheric association also demands attention for their great importance for rhizosperic bio-community. Nematophagous fungus mimics olfactory cues of sex and food to lure its nematode prey and has nematocidal value..(Hsueh.et.al.2013).Within this work the nematode community during summer season will be highlighted in different blocks of South 24 Parganas district of West Bengal, associated with paddy. The nematode – mycorrhizza association will reflect the ecosystem-health of different paddy field in the district. The serious pests of rice will be identified and accordingly control measures may be taken against them. The rice production will be enhanced and GDP of the country will be uplifted.

So, the intention of the present study will be isolation and identification of nematode fauna (parasitic as well as free living) at rhizospheric soil of paddy along with the mycorrhizzal association observation in different block including measuring the relationship of mycorhizza with edhaphic factors. This will throw some light upon these important organisms that are responsible for plant and soil health. It will help to adopt control measures against the noxious pest of rice. This will ultimately be helpful to enhance the rice production of our state as well as country.

Present status of paddy cultivation.

West Bengal in India was also an immense pool of rice biodiversity (Chatterjee, et al. 2008). Up to 1970 more than 5000 folk rice variations had been conveyed form Bengal (Deb, 2005). Destruction was beginning in 1975 when modern High Yielding Varieties (HYV) were introduced. Borderline farmers were cultured HYVs only for upsurge making as a result 75% of folk varieties become disappeared from the rice fields (Gliessman, 2007). Folk assortments are valuable as they hold paragon of genetic substantial which may demonstrate valuable in forthcoming crop expansion and enhancement programs. Several workers have been working on importance of conservation of folk rice varieties. Deb (2005), Sinha and Mishra (2014, 2015), Chakraborty et al. (2012) etc. worked on diversity of folk rice varieties of West Bengal and also pointed out their gradual squalor. Misra et al. (2010) have worked on grade and preservation of rice diversity of Orissa. Kumar et al. (2013), Kumar et al. (2015) and Patra (2000) had been reported genetic changeability of rice of Allahabad agroclimatic region, Bihar and Orrisa respectively. Hattori et al. (2011), Atlin et al. (2006) Patra and Dhua (2010), Karmakar et al. (2012) worked on diverse abiotic pressure (drought, food) resilient capacity of various outdated rice varieties. Frankel (1973), Juliano (1993) worked on esthetical and medicinal values of outmoded diversities and also gave predilection to the protection of these varieties. Maintenance of genetic diversity is the essential of sustainable agriculture. Traditional assortments have their own use value, option value, culture value and existence value (Brush et al. 1992).

In present changing environmental condition when agriculture come into a susceptible stage, protection and application of existing old variations is only method to evolve new recover varieties. Cyclone Aila of 2009 had took people's back to salt-tolerant varieties but they had become rarely available in the Sunderbans region by that time.

The report 2017 research project said that the Dudhersar variability, which is of intermediate salt tolerance superiority, was full-grown in many portions of the Sundarbans delta as it raises a best value in the bazaar and thus farmers get remunerated contempt low harvests. However, highly salt-tolerant variations like Darsal, Nona Bokra and Talmugur, found to be cultured in squares of the Sundarbans, are not prevalent because they cannot raise a good price in the market (Ghosh et al, 2017). One problem with rising HYVs in the Sundarbans area is the obligation of chemical fertilisers, which in turn upsurges soil salinity, said Amalesh Mishra, a retired zoologist from the Zoological Survey of India who heads an NGO named Paribesh Unnayan Parishad."The so-called HYVs and chemical fertilisers are not appropriate for the Sundarbans where the soil has extreme salinity," said Mishra, adding that it was only a amalgamation of salt tolerance and high-price-fetching potentials in rice that can transport a long-term resolution to Sundarban's difficulties with food security and income.

Some nematode defenseless varieties of paddy are cultivated in India *viz.*IR-64, Naveen, Dharitri, Mashuri, Sarala, Geetanjali, Tapaswini, Pooja, Ratna, Pusa etc. Except Ratna, none of these varieties are so popular in West Bengal (Subudhi, 2017). Three varieties, Zhonghua 11 (aus), Shenliangyou 1 (hybrid aus) and Cliangyou 4418 (hybrid indica) were experiential highly resistant to M. graminicola under both pot and field situations. M. graminicola pierced less often into highly hardy varieties and failed to mature into females more often than with susceptible varieties (Li-ping 2018). The recurrent parent Teqing and the donors Type 3, Zihui 100 and Shwe Thwe Yin Hyv were resilient to the nematode in India (Prasad et al. 2006). *Oryza longistaminata* and three consents of *Oryza glaberrima* (TOG7235, TOG5674, TOG5675) in the Philippines were originate to be unaffected to M. graminicola (Soriano et al. 1999), and two commonly full-grown rice cultivars, Masuli and Chaite-6, were abstemiously impervious to M. graminicola in Nepal (Sharma-Poudyal et al. 2004).

Activation of the jasmonic acid pathway via exterior submission of methyl jasmonate is an actual way for defending rice from root-knot nematode infection (Nahar et al. 2011; Kyndt et al. 2012). In addition, a series of defence-related pathways were muscularly triggered in the sick root system at the preliminary period (Kyndt et al. 2014; Kumari et al. 2016). Furthermore, Nahar et al. (2011) established that ethylene (ET) plays a role in security against M. graminicola in rice plants, and pharmacological reserve of ET biosynthesis in rice led to a suggestively improved vulnerability to the nematode. Brassinosteroids are tangled in plant innate immunity, and an exogenic supply of high absorptions of epibrassinolide invoked systemic defence against M. graminicola (Nahar et al. 2013). Therefore, alterations in M. incognita infection and development in unaffected and susceptible rice varieties can be attributed to changes in molecular and histological responses to nematode contamination among these plants (Cabasan et al. 2012).

Rice can accumulate a large number of secondary metabolites, such as phenolic acids, flavonoids, terpenoids, steroids, and alkaloids (*viz, p*-hydroxybenzoic acid, caffeic acid, protocatechuic acid, ferulic acid, sinapic acid, syringic acid, vanillic acid, protecatechuic acid, *p*-coumaric acid, and ferulic acid). These molecules play numerous physiological and ecological roles (i.e., antimicrobial, insecticidal, nematocidal, growth regulatory, and allelopathic activities). Rice terpenoids purposes as allelochemicals. Rice plants accrue phenyl amides in response to a pathogen bout, said Wang (2018). But plant parasitic nematoes still persists.

About Nematodes: Nematodes belong to the phylum Nematoda and are one of the most copious groups in the soil and litter, having a noteworthy protagonist in determining the microbial communities in soil (Torr.et.al.,2007). According to Bohra and Baqri (1997), Soil nematodes are unrivaled by other metazoans because of the abundance and distribution in a wide range of habitats from mountain peaks to marine beds. Nematodes can be animal parasitic, phyto parasitic, saprophytic, predatory, carnivorous, and even cannibalistic. In soil or rhizosphere of plants mainly bacteriovorus, fungivorous, omnivorous plant parasitic nematodes are found. In case of rice plant several nematode pests like *Aphelenchoides besseyi* (white tip nematode), *Ditylenchus angustus* (stem nematode), *Meloidogyne graminicola* (root knot nematode), etc. are known to cause deleterious effect s over the years (Animal resource of India, 1991). It has been reported by DeRuiter.et.al.,1993, that about 40% mineralization of nutrients in a certain ecosystem is due to nematodes and other soil organisms that feed on bacteria and fungi. Apart from their parasitic forms, bacteriovore, fungivore and omnivore nematodes are now considered as important contributing members in microbial biomass turnover in soil (Bardgett et.al.,1999). Now it has been widely putative that nematodes have an optimistic effect not only on soil but in other ecosystems also (Bradgett et. al.,1999; Ferris, 2001; Yeates ,2003). Nematode diversity is also considered as a bioindicator of soil conditions and it is expected that the diversity of nematodes and the soil health are positively correlated (Yeates,2003). The omnipresence and diversity of nematodes are used to evaluate the influence of diverse disturbances in ecosystems like chemical and organic pollutants and even organic enrichment.

EL-Borai et.al. (2003) reported that *Tylenchus semipenetrans* (Cobb, 1913), together with *B. megaterium* and *Burkholderia cepacia* protected plants from fungal pathogens. Mao et. al. (2006) stated that bacteria feeding nematodes accelerated the growth of tomato seedlings. Cheng et. al.,2016 proved that the rice soil inoculated with bacteria and bacterial feeding nematodes showed significant surges in nitrogen mineralization and IAA production, hence growth of the plant occurred. This phenomenon is suggested to be the consequence of nematode grazing upon bacteria. Some reports also suggested that some genes of root knot nematode *Meloidogynae* sp. are bacterial origins and results from horizontal gene transfer.

About rhizospheric zone of rhizosphere of soil: Soil is a substantial self-possessed of five ingredients — minerals, soil organic matter, living organisms, gas, and water. Soil minerals are unglued into three size modules — clay, silt, and sand. The rhizosphere generally refers to the share of soil found adjacent to the roots of living plants. The rhizosphere is issue to the influence of chemicals excreted by roots of existing plants and the microbial community in this microzone. Its province fluctuates for different plant species and for age and morphology of roots. Contingent on plant species, the width of the rhizosphere zone has been revealed to extend from 2 to 80 mm away from the root shallow. The soil in the rhizosphere provisions a typically miscellaneous and closely settled microbial community and is subject to chemical transformations caused by the company of root exudates and metabolites of microbial degradation.

The rhizosphere, first designated in 1904 by Lorentz Hiltner, has been the emphasis of rigorous research for many years as of its importance in plant nutrition and pathogenesis. More recently, investigate on the rhizosphere has been rapt toward its influence on controlling the persistence, mobility, and bioavailability of contaminants in soils. The rhizosphere is a self-motivated region administered by multifaceted interactions between plants and the organisms that are in close connotation with the derivation. The arrangement and decoration of root exudations affect microbial commotion and population numbers, which in turn have an impression on the nematodes and microarthropods that stake this environment. Beneficial or harmful relationships exist between rhizosphere organisms and plants, which ultimately affect root function and plant growth. In addition, the rhizosphere may embrace organisms that do not directly benefit or harm plants but clearly influence plant growth and efficiency. A better considerate of the soil–root and soil–seed edge is needed to accomplish microorganisms, upsurge plant growth, and moderate the influence of plant production and agriculture on the environment. The reimbursements of studying the rhizosphere include the practice of plant growth-promoting organisms and the destruction of plant diseases and weeds using biocontrol mediators. Rhizosphere organisms can also be cast-off to augment the establishment of steady soil aggregates and as bioremediation negotiators of contaminated soils. With greater considerate of the ecology and biota in the rhizosphere, this zone of amplified nutrients, biotic commotion, and interactions can be wrought to improve plant throughput and environmental excellence. (A.C. Kennedy, L.Z. de Luna, in Encyclopedia of Soils in the Environment, 2005)

The plant rhizosphere harbours a diverse reservoir of culturable microorganisms that can be browbeaten to assistance mankind. Many rhizospheres' microbes profit crop production, reducing the obligation on chemical fertilizers to accomplish high fecund yields. Others protect plants from the ravages of pathogens and the diseases they cause. Consumption of these beneficial examples is fully consistent with sustainable agriculture, where the goal of paramount importance is to employ natural processes that promote the crop's output without irreparably damaging the natural resource improper where the crop can be full-grown.

Among the many recent discoveries in rhizosphere research is the ominous finding that certain potential human pathogenic microorganisms are also successful residents of this nutrient-enriched plant soil milieu, and this ecology poses possible public health death-traps for the people (both producers and consumers) who happenstance them. An interesting thought for future exploration is whether the rhizosphere also provisions populations of human protective HHER (human health-endorsing rhizobacteria).(F.B. Dazzo, S. Ganter, in Encyclopedia of Microbiology (Third Edition), 2009)

Rhizosphere bioremediation indications to biodegradation of pollutants by microorganisms in the root precinct. Plants are known to intensification both microbial realities and metabolism in soil, resultant in amended biodegradation crusade. Numerous mechanisms explain the heightened biodegradation in the rhizosphere: The root revenue increases soil organic carbon, stimulating microbial activity and co-metabolism of toxic pollutants; root exudates contain small organic acids, alcohols, and phenolic compounds that favor solubilization and bioavailability of hydrophobic pollutants; root tissues and microorganisms also conceal catabolic enzymes, such as peroxidases and laccases, elaborate in biodegradation mechanisms; explicit compounds unconfined by roots persuade microbial enzymes and rouse biodegradation; finally roots familiarize oxygen in the rhizosphere, which is compulsory for oxidative biodegradation by oxygenases [B. Van Aken, in Comprehensive Biotechnology (Second Edition), 2011)

The rhizosphere micro zone is illustrious from the majority soil zone, more habitually known as the edaphosphere, by boosted microbial activity and improved absorption of root exudates. Nevertheless, it is somewhat tough to separate this zone materially from the root superficial or rhizoplane. The rhizosphere consequence is uttered quantitatively as the ratio of the number or activity of microorganisms or level of root exudates in rhizosphere soil (R) to that in the edaphosphere soil (E), i.e., the R / E ratio. The R / E ratio for microorganisms and root exudates is often initiate to range, correspondingly, from 2 to 20 and from 5 to 100, representing enhanced microbial bustle in the rhizosphere.

Root exudates are known as one of the most vital issues upsetting microbial growth in the rhizosphere. For example, cell numbers are numerous orders developed in the root zone than in the background soil lacking plants. The microbial community is more diverse, active, and synergistic than in no rhizosphere soil. Root exudates can also selectively influence the growth of bacteria and fungi that colonize the rhizosphere by quota as selective growth substrates for soil microorganisms. (B-. J. Koo, ... C.D. Barton, in Encyclopedia of Soils in the Environment, 2005)

Rhizosphere also known as the microbe storehouse is the soil zone surrounding the plant roots where the biological and chemical structures of the soil are influenced by the roots. The rhizosphere is coined more than hundred years ago by Hiltner in 1904. It is a hot spot for microorganisms, where unadorned, penetrating exchanges take place amid the plant, soil, and microfauna (Antoun and Prévost, 2005; Kumar et al., 2015). They may have optimistic, adverse or unbiassed outcome on plant development (Ordookhani and Zare, 2011). Plant progress and efficiency is exceedingly affected by these relations. Dissimilar type of microorganisms such as bacteria, fungi, protozoa, algae coexist midst them. Out of them, plant growth promoting bacteria (PGPR) are most copious among all others in the rhizosphere. It is finely reputable that the bacterial population in the rhizosphere are advanced than in bulk soil (Bahadur et al., 2017). Plants take up water and nutrients through rhizosphere where microorganisms interrelate with root transudes. Root exudates include carbohydrates, sugar, organic acids, vitamins, flavonoids, nucleotides, enzymes, hormones, and volatile compounds inorganic ions, gaseous molecules. The exudates act as messengers that stimulate interactions between roots and soil organisms. Thus, the rhizosphere has emerged as a versatile and dynamic ecological environment in the soil with high microbial diversity. (Mahendra Prasad, ... Lokesh Kumar Jat, in PGPR Amelioration in Sustainable Agriculture, 2019)

The rhizosphere is the slender region of soil or substratum that is directly prejudiced by root secretions and allied soil microorganisms recognized as the root microbiome. The rhizosphere involving the soil pores comprises many bacteria and other microorganisms that provender on sloughed-off plant cells, called rhizodeposition, and the proteins and sugars unconfined by roots, labelled root exudates. This interdependence primes to extra complex interactions, influencing plant development and rivalry for capitals. Widely the nutrient cycling and disease conquest by antibiotics obligatory by plants, occurs directly together to roots due to root exudates and metabolic products of symbiotic and pathogenic communities of microorganisms. The rhizosphere also delivers space to produce allelochemicals to control neighbours and families.

Plants inspiration the three-dimensional structure in soil by the development of their roots (Angers and Caron, 1998). Further, they figure the chemical configuration of the rhizosphere and afford microbial growth substrata by rhizodeposition (Lynch and Whipps, 1990; Hirsch et al., 2013; Philippot et al., 2013). Contingent on the plant species, between 20 and 50% of plant photosynthate is ecstatic belowground (reviewed by Kuzyakov and Domanski, 2000), and an average of 17% is unrestricted to the soil environment (reviewed by Jones et al., 2009). In reappearance for growth substrates, rhizosphere microorganisms advantage plants by providing nutrients, phytohormones, suppressing phytopathogens or increasing resilience to abiotic stress such as heat, high salt, or drought (Welbaum et al., 2004; van der Heijden et al., 2008; Yang et al., 2009; Mendes et al., 2011; Nihorimbere et al., 2011; Haney et al., 2015). The microbial community is also principally answerable for the decomposition of organic matter in soil (Kuzyakov, 2002), which has penalties for biogeochemical cycling, soil construction, soil fertility and atmospheric trace gas foundation (Conrad, 1996; Hinsinger et al., 2009).

Rice varies from most crops in that it is characteristically cultured in flooded soil, resulting in oxic and anoxic zones within the rice rhizosphere that choice for specific physiological groups of microorganisms with either aerobic, anaerobic, or facultivative metabolism (Brune et al., 2000). Methanogenesis in the rhizosphere and bulk soil of rice fields outcomes in rich methane (CH4) production, with rice agriculture presently contributing ∼10% of the global CH4 budget (Conrad, 2009). The main substrata for methanogens are acetate or H2 + CO2 formed from the breakdown of composite carbon by the microbial community, including fermenters and acetogens (McInerney et al., 2008). Approximately 60% of CH4 formed in rice grounds originates from root exudates or decaying root substantial (Watanabe et al., 1999).

The microbial communities inhabiting the rice field ecosystem have been designated previously. For instance, the microbes within the rice root inside, the rhizoplane and the rhizosphere have been analysed (Edwards et al., 2015). The microbial communities in various zones, such as rhizosphere, anoxic bulk soil, and oxic surface soil have been stated (Großkopf et al., 1998; Lüdemann et al., 2000; Lu et al., 2004; Asakawa and Kimura, 2008; Breidenbach and Conrad, 2015; Lee et al., 2015). The rice phyllosphere microbial community by 16S rRNA pyrotag sequencing (Ren et al., 2014) as well as endophytic and rhizospheric communities with metagenomic and metaproteomic approaches (Knief et al., 2012). Also, specific purposeful groups of microorganisms, such as methanogens (Ramakrishnan et al., 2001;) and methanotrophs (Henckel et al., 1999; Eller and Frenzel, 2001; Ho et al., 2011;), have been extensively analysed in rice systems. However, none of these studies focused on the influence of the rice plant on the entire microbial community and over some progress stages of rice.

Rhizodeposition by rice plants has been designated (Aulakh et al., 2001; Wu et al., 2009) and shown to augment microbial movement in the rhizosphere equated with bulk soil (Butler et al., 2003). Oxygen is also unconfined from rice roots (Frenzel et al., 1992; Colmer and Pedersen, 2008) and aids as an electron acceptor for aerobic microorganisms and is possible to motivation the microbial populations and the chemical transformations that transpire. The size and configuration of organic molecules unrestricted from roots changes somewhat with rice plant progress phase (Aulakh et al., 2001), which in theory could also origin temporal moves in the rhizosphere microbial community.

About mycorrhiza and mycorrhizosphere:

The rhizospheric region of greatest of the terrestrial living plants is populated by some root colonizing fungi, this pervasive, symbiotic connotation between the fungi and root of the plant and known as mycorrhiza. The term mycorrhiza was first devised in the year 1885 by Bernhardt Frank when he made an effort to describe the special root structures. Based on equally morphological structures and physiological connection among the fungus and the plants there are normally two different types of mycorrhizas known as ecto and endomycorrhiza.

Normally the endomycorrhizae or AM (i.e arbuscular mycorrhiza) are mostly seen related with angiosperms. Although sometimes the overtone is also seen with gymnosperms pteridophytes, bryophytes, lycopodium, mosses and ferns (Smith et al., 1997). VAM (i.e Vesicular Arbuscular mycorrhiza) not all endomycorrhizae are seen to produce vesicles but all are known to produce arbuscules. Fossil records and paleontological evidences pathway derivation of mycorrhizae to the 3eroxidise era which dates posterior to around 450 to 500 million years ago. (Remyet al., 1994; Redecker et al.,2000). It was conjectured by Simon et al., in 1993 that the prehistoric symbiotic connotation abetted in plant colonization. And the theory was reinforced by the attainment of countless nutrients, minerals and phosphate via the channel molded between the plant and the soil concluded by the fungi. The theory was also buoyed with the indications that during land colonization pteridophytes and bryophytes were the plants on the conversion sector and till date a huge quantity of AM associations have been noted. (Read et al., 2000; SchüBler, 2000). Widespread study on the 'mycorhizosphere' habitat exposed that the symbiotic relationship both physically and chemically inspiration the assembly of rhizosphere, it's neighboring communities and the ecosystem. (Lin et al., 1991). Generally, the AM fungi fit from the cluster Zygomycetes and order Glomales. Their name arbuscular fungi originate from the development of exclusive characteristic structure called arbuscules. These are mainly seen within the cortical tissue province of the plant root and sometimes in case of subordinate groups of plant within the settled mycothallis. (Smith et al., 2008) These arbuscules are intra- radical spirals or vesicles (modified form of fungal hyphae) providing a distended expanse for food, water, nutrition conversation along with sometimes acting as stowage organs as well. This establishment of arbuscules can be accredited to the special feature of AM mycorrhizae i.e intensification in plant root outward area resulting from the widespread hyphal growth. Survivability of root colonized plants in risky condition like scarcity or in a nutrient deficit can be recognized to the momentous growth in the shallow area of root. The attendance of AM overtone in agricultural soil particularly in tropical and subtropical region is meaningfully high secretarial up to the percentage of 5-50% all microbial interdependence in agricultural soils. An estimated evolution rate approximation of additional radical hyphae shows that in around 1gram of grassland soil as much as 100m of AM hyphae can be originate. (Mohammadi K et al.,2011). Ectomycorrhiza are found as a symbiotic connotation between gymnosperms and shrubs. On a phylogenetic ladder ectomycorrhiza specifically ericoid mycorrhiza stand at a much later stage of evolution. (Tagu et al.,2002; Perotto et al.,2002). This is AM which are monophyletic in source whereas ectomycorrhizae are polyphyletic in derivation. (Fitter et al., 1996). EM is mostly gotten occurring in families of gymnosperms like Pinaceae and in some designated angiosperm families like Dipterocarpaceae and Betuleace etc. Generally, the fungus part in EM association accounts for around 30% of complete microbial biomass in forest soil especially in boreal and temperate zones. (Mohammadi K et al., 2011). In EM overtone the fungal companion systems a sheet or fungal mantle over the root of the plant however in certain number of species a network of hyphae or Hartig's net assembly is also perceived. A third type of connotation known as ecto- endomycorrhizae is also known. Here the sheath is almost reducing to nil however prominent Hartig's net are present and prominent hyphal penetration within the cortical cells also occurs.

The mutualistic relations between AM and agriculturally vital yields have shown the credible to upsurge crop output, thereby playing a key role in the operative and sustainability of agro-ecosystems (Gianinazzi et al, 2010). The utmost significant function of these symbiotic connotations involves the transmission of nutrients such as organic carbon (C), in the procedure of sugars and lipids (Jiang et al, 2017; Luginbuehl et al, 2017) to the fungi by the plants, and the assignment of phosphorus (P) and nitrogen (N) to the plants by the fungi (Smith and Read, 2008). AM-mediated enhancement in mineral acceptance may lead to augmented growing and expansion of plants, and may discuss confrontation to abiotic and biotic stress (Liu et al, 2007; Smith and Read, 2008; Gianinazzi et al, 2010). In this respect a checked on the molecular crosstalk on numerous phytohormones and secondary metabolites in plants shown raised levels of jasmonate along with raised transcription of cell specific levels of jasmonate biosynthetic pathway genes, improved production of apocarotenoids, and secondary isoprenoids. (Strack et al.,2003). In addition to these aids to plants, AM may recover soil edifice, ameliorate scarcity and salinity stress, and distress the assortment of plant communities (van der Heijden et al, 1998; Rillig and Mummey, 2006; Smith et al, 2010). Glomalin was acknowledged at USDA on hyphae (hair-like projections) of arbuscular mycorrhizal fungi (AMF). These fungi are antique microorganisms that transformed with plants to succour in acquiring nutrients, specifically steady nutrients like phosphorus (P). The benefits of AM may be grave to cumulative agricultural yields and efficiency in a low-input means.

The mycorrhizosphere is the segment of soil prejudiced by roots settled by mycorrhizal fungi (Fig. 14.3) and the mycorrhizosphere effect on other rhizosphere populaces is an area of much current courtesy (Priyadharsini et al., 2016). This is mostly because it is nearly incredible to understand the rhizosphere outcome on bacterial communities without joining mycorrhizal fungi.

Conclution:

Nematodes in the genera *Aphelenchus*, *Aphelenchoides*, *Ditylenchus*, and *Tylenchus* are among the most mutual fungivorous nematodes. Antagonistic communications between fungi and nematodes are as numerous as they are varied. For example, many nematodes, such as *Aphelenchus avenae*, *Aphelenchoides spp.*, and *Paraphelenchus acontioides*, can feed on a diversity of fungi. These are commonly referred to as fungivores nematodes (Lamondia J., 2016). In contrast, a number of fungal species such as *Arthrobotrys oligospora* can prey on nematodes and their eggs, consuming them as food. Such fungi are known as nematophagous fungi (Su H., 2017). In the case of fungi–nematode interactions, sequencing of the genomes of the nematode female and egg parasite *Pochonia chlamydosporia*; the nematode-trapping fungi *Arthrobotrys oligospora*, *Monacrosporium haptotylum*, and *Drechslerella stenobrocha*; and the facultative nematode endoparasite *Heterodera minnesotensis* have greatly contributed to our considerate of the evolutionarily distinct strategies of fungal pathogenesis in contradiction of nematodes. Fungi that parasitize nematodes are common soil saprophytes, attacking primarily the sedentary stages (female and egg stages) of nematodes or deskbound nematodes, such as *Heterodera*, *Globodera* and *Meloidogyne*. Nematode-toxic fungi have nematode-immobilizing activity and can slay their nematode swarms by producing toxins (Basel 2020). Combination of two Arbuscular mycorrhizal fungi (AMF) *Glomus fasciculatum* and *G. mosseae* and three nematode antagonistic fungi viz., *Arthrobotrys oligospora*, *Purpureocillium lilacinum* (= *Paecilomyces lilacinus*) and *Pochonia chlamydosporia* on sugarcane cv. 86032 appears to be a latent blend for the manager of root lesion nematode *Pratylenchus zeae* (Sankaranarayanan,2021). *Arthrobotrys oligospora* imprisonments nematodes using adhesive polymers present on distinct hyphae (traps) which formulate a three-dimensional network. Gel chromatography of the excerpts revealed that the major carbohydrate-containing polymer(s) had a molecular mass of as a minimum 100 kDa, encompassing neutral sugars (75% by mass, including glucose, mannose and galactose), uronic acids (6 %) and proteins (19 %). There was additional polymer in mycelium containing trap-bearing cells than in vegetative hyphae. SDS-PAGE of the mined polymers showed that the trap-forming cells contained at least one protein, with a molecular physique of approx. 32 kDa, not contemporary on vegetative hyphae (Tunlid,1991). Mycorrhiza is good bio-fertilizer and eco-friendly bio-control measure, holding sustainable development (Field et al., 2020). It also creates suitable microenvironment that helps to take entry of other nematophagous fungi (Zhang et. al., 2020); which helps to control plant parasitic nematodes (PPN) (Poveda, 2020; Lawal.et al., 2022). Mycorrhiza culture is very cheap and it can be used as bio-control agent against plant parasitic nematodes in paddy fields. It may help to enhance rice production and to achieve Sustainable Development Goal 2 i.e., “Zero Hunger” and Goal 3 i.e., “Good Health and Well-Being” with new source of employments.

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References:

Angers, D., and Caron, J. (1998). Plant induced changes in soil structure: processes and feedbacks. *Biogeochemistry* 42, 55–72. doi: 10.1023/A:1005944025343

Anonymous. 2010. Presented in National Conference on Kharif Campaign 2010, 18th & 19th March, 2010, New Delhi, Presented by Depertment. of Agriculture, Government of West Bengal.

A.C. Kennedy, L.Z. de Luna, in Encyclopedia of Soils in the Environment, 2005)

Animal resource of India, 1991. Zoological Survey of India.

Anandan, A, Rajiv, G, Eswaran,R. and Prakash,M. 2011. Genotypic variation and relationships between quality traits and trace elements in traditional and improved rice (Oryza sativa L.) genotypes. Journal of Food Science, 76(4): H122–H130.

Antoun, H. and Prevost, D. (2005) Ecology of Plant Growth Promoting Rhizobacteria. ın: Siddiqui, Z.A., Ed., PGPR: Biocontrol and Biofertilization, Springer, Berlin, 1-38.https://doi.org/10.1007/1-4020-4152-7_1

Asakawa and Kimura, 2008.Ecology of viruses in soil: Past, Present, Future Perspectives. 54(1). 1-32. https://doi.org/10.1111/j.1747-0765.2007.00197.x

Atlin, G. N, Lafitte, H. R, Tao, D, Laza, M, Amante, M. and Courtois, B. 2006. Developing rice cultivars for highfertility upland systems in the Asian tropics. Field Crops Research, 97:43-52.

Aulakh. M. S., Wassmann. R., Bueno. C., Rennenberg. H. 2001. Impact of root exudates of different cultivars and plant development stages of rice (Oryza sativa L.) on methane production in a paddy soil. Plant and soil.230. 77-86.

Ayoub, S.M. (1980). Plant nematology: an agricultural training aid. (Revised). 195

Brush, S. B, Taylor, J. E. and Bellon, M. R. 1992. Biological diversity and technology adoption in Andean potato agriculture. Journal of Development Economics, 39:365– 387.

Baqri. H. Q. and Bohra. P. 1997. Studies on plant and soil nematodes associated with crops of economic importance in Gujrat. Records of the Zoological Survey of India.

B. Van Aken, in Comprehensive Biotechnology (Second Edition), 2011)

B-. J. Koo, ... C.D. Barton, in Encyclopedia of Soils in the Environment, 2005

Bahadur. A., Ahmad. R., Afzal. A., Feng. H., Suthar. V., Batool. A., Khan. A. Mahmood-ul-Hassan. 2017. The influences of Cr-tolerant rhizobacteria in phytoremediation and attenuation of Cr (VI) stress in agronomic sunflower (Helianthus annuus L.). Chemosphere. 179. 112-119.

Brune, A., Frenzel, P., and Cypionka, H. (2000). Life at the oxic-anoxic interface: microbial activities and adaptations. *FEMS Microbiol. Rev.* 24, 691–710. doi: 10.1016/S0168-6445(00)00054-1 Breidenbach and Conrad, 2015. Seasonal dynamics of bacterial and archaeal methanogenic communities in flooded rice fields and effect of drainage. Front Microbiol. 8; 5:752. doi: 10.3389/fmicb.2014.00752.

Breidenbach, B., and Conrad, R. (2015). Seasonal dynamics of bacterial and archaeal methanogenic communities in flooded rice fields and effect of drainage. *Front. Microbiol.* 5:752. doi: 10.3389/fmicb.2014.00752

Butler, J. L., Williams, M. A., Bottomley, P. J., and Myrold, D. D. (2003). Microbial community dynamics associated with rhizosphere carbon flow. *Appl. Environ. Microbiol.* 69, 6793–6800. doi: 10.1128/AEM.69.11.6793-6800.2003Basel 2020

Bose (2020). Reviving Our Rice Bowl: Bengal Farmers Preserve 200+ Traditional Rice Varieties. Retrieved from: https://www.thebetterindia.com/208183/bengal-traditional-rice-seeds-growing-yield-organic-farmers-lakhs-india

Cavagnaro. T. R., Gao.L.L.,Smith. F.A., Smith. S.E.,2001, Morphology of Arbuscular Mycorrhizas Is Influenced by Fungal Identity. The New Phytologist Vol. 151, No. 2 (Aug., 2001), pp. 469-475. https://www.jstor.org/stable/1353798

Cavagnaro (2008). The role of arbuscular mycorrhizas in improving plant zinc nutrition under low soil zinc concentrations: a review. *Plant and Soil*. 304, No. 1/2.315-325.

Charkravorty, A and Ghosh, P. D. 2012. Genetic divergence in landraces of rice (O. sativa L.) of West Bengal. India. J. Crops and Weed, 8(2): 23-28.

Chatterjee, S. D, Adhikari, B, Ghosh, A, Ahmed, J, Neogi, S. B. and Pandey, N. 2008. The rice bio-diversity in West Bengal. Department of Agriculture, Govt. of West Bengal, pp. 50.

Cheng. Y., Jiang. Y., Wu. Y., Valentine. T. A., Li. H.,2016. Soil Nitrogen Status Modifies Rice Root Response to Nematode-Bacteria Interactions in the Rhizosphere. PLoS One.11(2):e0148021. doi: 10.1371/journal.pone.0148021PMCID: PMC4739600

Cabasan. M. T. N., Kumar. A., Waele D. (2012). Comparison of migration, penetration, development and reproduction of Meloidogyne graminicola on susceptible and resistant rice genotypes. Nematology, 14, 405–415.

Cobb, N. A. (1913). New Nematode genera found inhabiting fresh water and nonbrackish soils. Journal of the Washington Academy of Sciences.

Conrad, R. (1996). Soil microorganisms as controllers of atmospheric trace gases (H2, CO, CH4, OCS, N2O, and NO. Microbiol. Rev. 60, 609–640.

Colmer, T. D., and Pedersen, O. (2008). Oxygen dynamics in submerged rice (Oryza sativa). New Phytol. 178, 326–334. doi: 10.1111/j.1469-8137.2007. 02364.x

DeRuiter.P. Schroter. D., Wolters. V.,1993, C and N Mineralisation in the Decomposer Food Webs of a European Forest Transect. Oikos.102(2).294-308

Deb, D. 2005. Seeds of Tradition, Seeds of Future: Folk Rice Varieties from East India. Research Foundation for Science Technology & Ecology. New Delhi, pp. 12-14.

EL-Borai K. F.,2003. Plant Parasitic Nematodes in Subtropical and Tropical Agriculture. 2nd Edition. CABI International.UK

Eller and Frenzel, 2001. Changes in Activity and Community Structure of Methane-Oxidizing Bacteria over the Growth Period of Rice. American Society for Microbiology. DOI: https://doi.org/10.1128/AEM.67.6.2395-2403.2001

Edwards. J.,Johnson. C., Santos-Medellin. C., Sundarsan. V., 2015. Structure, variation, and assembly of the root-associated microbiomes of rice. Howard Hughes Medical Institute and The University of North Carolina at Chapel Hill, Chapel Hill, NC. 112(8). E911-E920.

FAO IFAD, UNICEF, WFP and WHO (2019). The State of Food Security and Nutrition in the World 2019. Safeguarding Against Economic Slowdowns and Downturns. (Rome, FAO) Retrieved from: http: //www.fao.org

FrankelR. J.,Shouvanavirakul. P. (1973). Water consumption in small communities of northeast Thailand. Water Resources Research Volume 9, Issue 5 p. 1196-1207. https://doi.org/10.1029/WR009i005p01196

Ferris. H., Bongers. T., de Goede.R.G.M., 2001. A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Applied Soil Ecology.18.13-29.

F.B. Dazzo, S. Ganter, in Encyclopedia of Microbiology (Third Edition), 2009.

Frenzel, P., Rothfuss, F., and Conrad, R. (1992). Oxygen profiles and methane turnover in a flooded rice microcosm. Biol. Fertil. Soils 14, 84–89. doi: 10.1007/BF00336255;

Fitter. A. and Williamson. M., 1996. The Varying Success of Invaders. Ecology 77(6):1661-1666. DOI:10.2307/2265769

Field. J. K., Daniell. T., Johnson. D., Helgason. T., (2020). Mycorrhizas for a changing world: Sustainability, conservation, and society. Plants, People, Planet.2(2): 98-103. Retrieved from: https://doi.org/10.1002/ppp3.10092

Gantait. V.V., Roy. P., Mondal. S., Chatterjee. S. (2018). A Review on Diversity and Distribution of Nematodes Associated with Paddy in West Bengal, India. Advances in Fish and Wildlife Ecology and Biology. 305–327

Ghosh. S., Chattopadhyay.K. S. -A study of Indigenous Rice Varieties in Sunderland Delta and Their role in Ensuring Local Food Security in the face of Climate Change Threats.- 2017 research project by Visva-Bharati university

Gliessman, Stephen B. 2007. Agroecology: The ecology of sustainable food systems. CRC Press. Boca Raton/ LondonGhosh et al, 2017. 102.

Großkopf.R., Janssen. P.H., Liesack. W., 1998. Diversity and structure of the methanogenic community in anoxic rice paddy soil microcosms as examined by cultivation and direct 16S rRNA gene sequence retrieval. Am Soc Microbiol. Applied and environmental. 64 (3). 960- 969

Gianinazzi, S., Gollotte, A., Binet, M.-N., van Tuinen, D., Redecker, D., and Wipf, D. (2010). Agroecology: the key role of arbuscular mycorrhizas in ecosystem services. Mycorrhiza. 20, 519–30. Retrieved from: doi: 10.1007/s00572-010-0333-3

Hattori. Y., Nagai. K., Ashikari. M., (2011). Rice growth adapting to deepwater. Current Opinion In Plant Biology. 14. 100-105.

HILTNER, L. Ueber neuere Erfahrungen und Probleme auf dem Gebiete der Bodenbakteriologie und unter besonderer BerUcksichtigung der Grundungung und Brache. Arb. Deut. Landw. Gesell, 98:59-78. (1904)

Hirsch, P. R., Miller, A. J., and Dennis, P. G. (2013). "Do root exudates exert more influence on rhizosphere bacterial community structure than other rhizodeposits?" in Molecular Microbial Ecology of the Rhizosphere, ed. F. J. de Bruijn (Hoboken, NJ: John Wiley & Sons), 229–242.

Haney.H. C., Samuel. S. B. Bush. J.,Ausubel. M. F., 2015. Associations with rhizosphere bacteria can confer an adaptive advantage to plants. Nature Plants. 1. 15051.

Hinsinger, P., Bengough, A. G., Vetterlein, D., and Young, I. M. (2009). Rhizosphere: biophysics, biogeochemistry and ecological relevance. Plant Soil 321, 117–152. doi: 10.1007/s11104-008-9885-9

Hernández.M. E., Bernal. B., Mitsch.W.J., 2015.Ecosystem services of wetlands. International journal of Biodiversity Science, Ecosystem, Service And Management.11(1). https://doi.org/10.1080/21513732.2015.1006250

Henckel. T., Dunfield. P.F., Liesack. W., Knowles. R.Conrad. R.,1999. High-Affinity Methane Oxidation by a Soil Enrichment Culture Containing a Type II Methanotroph. Applied and Environmental Microbiology.
DOI: https://doi.org/10.1128/AEM.65.3.1009-1014.1999

Ho. A., Luke. C., Frenzel. P.,2011. Recovery of methanotrophs from disturbance: population dynamics, evenness and functioning. The ISME journal.5. 750-758.

Hsueh. P., Mahanti. P., Schroeder. F.C., Sternberg. P.W. (2013). Nematode-trapping fungi eavesdrop on nematode pheromones Current biology. 23(1):83-6. Retrieved from: DOI: 10.1016/j.cub.2012.11.035

Juliano BO, 1971. A simplified assay for milled rice amylose. Cereal Sci. Today, 16: 334-339.

Juliano (1993). Improving Food Quality of Rice. International Crop Science I.89.

https://doi.org/10.2135/1993.internationalcropscience.c107

Jiang. Y., Liu. M., Zhang. J., Chen. Y., Chen. X., Chen. L., Li. H., Zhang. X., Sun. B.,2017. ISME journal. 11(12). 2705-2717. doi: 10.1038/ismej.2017.120

Jones.D.L.,Nguyen. C.,Finlay. R.D., 2009. Carbon flow in the rhizosphere: carbon trading at the soil–root interface. Plant Soil .321:5–33 DOI 10.1007/s11104-009-9925-0

Kumar, A, Rangare, N. R. and Vidyakar, V. 2013. Study of genetic variability of Indian and exotic rice germplasm in Allahabad agro climate. The Bioscan, 8(4): 1445-1451.

Kumar, S, Singh, N. K, Kumar, R. and Kumar, C. 2015. Genetic divergence analysis for morpho-physiological traits of rice (Oryza sativa L.) under drought condition. The Ecoscan, 9(1&2):653-658.

Karmakar, Joydip, Rajib Roychowdhury, Rup Kumar Kar, Debal Deb and Narottam Dey 2012. Profiling of selected indigenous rice (Oryza sativa L.) landraces of Rarh Bengal in relation to osmotic stress tolerance. Physiolology and Molecular Biology of Plants18: 125–132

Kuzyakov and Domanski, 2000. Carbon input by plants into the soil. Review. Journal of Plant Nutrition and Soil Science 163(4):421-431 DOI:10.1002/1522-2624(200008)163:4%3C421::aid-jpln421%3E3.0.co;2-r

Kuzyakov, 2002. Review: Factors Affecting rhizosphere priming effects. Institute of Soil Science and Land Evaluation, University of Hohenheim, Stuttgart, Germany.

Knief.C., Delmotte.N., Chaffron. S., Stark. M., Innerebener. G., Wassmann. R., Mering C.V., Vorholt. A. J., 2012. Metaproteogenomic analysis of microbial communities in the phyllosphere and rhizosphere of rice. *The ISME Journal*. 6, pages1378–1390

Kumari C, Dutta T K, Banakar P, Rao U. (2016). Comparing the defence-related gene expression changes upon root-knot nematode attack in susceptible versus resistant cultivars of rice. 6:22846. Retrieved from: DOI: 10.1038/srep22846

Kyndt T, Denil S, Haegeman A, Trooskens G, Bauters L, VanCriekinge W, De Meyer T, Gheysen G. (2012). Transcriptional reprogramming by root knot and migratory nematode infection in rice. New Phytologist, 196 (3): 887–900. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/22985291/#:~:text=doi%3A%2010.1111/j,2012%20Sep%2017.doi: 10.1111/j.1469-8137.2012.04311. x. Epub 2012 Sep 17.

Kyndt T, Fernandez D, Gheysen G. (2014). Plant-parasitic nematode infections in rice: Molecular and cellular insights. Annual Review of Phytopathology, 52:135–153. Retrieved from: DOI: 10.1146/annurev-phyto-102313-050111

Lee. H. J., Kim. Y. S., Kim. J. P., Madsaen. E. L., Jeon. C. O.,2014. Methane emission and dynamics of methanotrophic and methanogenic communities in a flooded rice field ecosystem. FEMS Microbiol Ecol;88(1):195-212. doi: 10.1111/1574-6941.12282

LaMondia J., Timper P. (2016). Interactions of microfungi and plant-parasitic nematodes. *Biology of Microfungi.* Springer International Publishing; Berlin/Heidelberg, Germany. Retrieved from: DOI:10.1007/978-3-319-29137-6_23

Lawal. I., Fardami. A. Y.Li-ping (2018). Evaluation of Chinese rice varieties resistant to the root-knot nematode Meloidogyne graminicola. *Journal of Integrative Agriculture 2018*. 17(3): 621–630. Retrieved from: https://doi.org/10.1016/S2095-3119(17)61802-1

Lawal. I., Fardami. A. Y., Ahmad. I. F., Yahaya S., Abubakar. A.S., Sa'id. M. A., Marwana. M., Maiyadi. K. A., (2022). A Review on Nematophagous Fungi: A Potential Nematicide for the Biocontrol of Nematodes. Journal of Environmental Bioremadiation and Toxicology.5(1): 26-31. Retrieved from: DOI:https://doi.org/10.54987/jebat.v5i1.677

Li-ping. Z., Zhong.D., De-liang.P.,Huan. P.,Ling-an. K.,Shi-ming. L., Ying. L., Zhong-cai. Li., Wen-kun. H., 2018. Evaluation of Chinese rice varieties resistant to the root-knot nematode *Meloidogyne graminicola.*

Journal of Integrative Agriculture.Vol. 17. (03): 621-630 DOI: 10.1016/S2095-3119(17)61802-1

Lynch and Whipps, 1990. Substrate flow in the rhizosphere. Plant and Soil. 129, 1–10

Lüdemann. H., Arth. I.,Liesack. W., 2000. Spatial Changes in the Bacterial Community Structure along a Vertical Oxygen Gradient in Flooded Paddy Soil Cores. Applied and Environmental Microbiology 66(2):754-62. DOI:10.1128/AEM.66.2.754-762.2000

Lee, H. J., Kim, S. Y., Kim, P. J., Madsen, E. L., and Jeon, C. O. (2014). Methane emission and dynamics of methanotrophic and methanogenic communities in a flooded rice field ecosystem. FEMS Microbiol. Ecol. 88, 195–212. doi: 10.1111/1574-6941.12282

Lu, Y., and Conrad, R. (2005). In situ stable isotope probing of methanogenic archaea in the rice rhizosphere. Science 309, 1088–1090. doi: 10.1126/science.1113435

Lee, H. J., Jeong, S. E., Kim, P. J., Madsen, E. L., and Jeon, C. O. (2015). High resolution depth distribution of Bacteria, Archaea, methanotrophs, and methanogens in the bulk and rhizosphere soils of a flooded rice paddy. Front. Microbiol. 6:639. doi: 10.3389/fmicb.2015.00639

Lu, Y., Murase, J., Watanabe, A., Sugimoto, A., and Kimura, M. (2004). Linking microbial community dynamics to rhizosphere carbon flow in a wetland rice soil. FEMS Microbiol. Ecol. 48, 179–186. doi: 10.1016/j.femsec.2004.01.004Lu and Conrad, 2005. In situ stable isotope probing of methanogenic archaea in the rice rhizosphere. Science;309(5737):1088-90. doi: 10.1126/science.1113435

Lu, Y., Rosencrantz, D., Liesack, W., and Conrad, R. (2006). Structure and activity of bacterial community inhabiting rice roots and the rhizosphere. Environ. Microbiol. 8, 1351–1360. doi: 10.1111/j.1462-2920.2006. 01028.x

Lundberg, D. S., Lebeis, S. L., Paredes, S. H., Yourstone, S., Gehring, J., Malfatti, S., et al. (2012). Defining the core Arabidopsis thaliana root microbiome. Nature 488, 86–90. doi: 10.1038/nature11237

Lin, X., E. George and H. Marschner, 1991. Extension of the phosphorus depletion zone in VA-mycorrhizal white clover in a calcareous soil. Plant Soil., 136: 41-48

Liu W., Zhang Z., Wan S. Predominant role of water in regulating soil and microbial respiration and their responses to climate change in a semiarid grassland. Glob. Change Biol. 2009; 15:184–195

Mahendra Prasad, ... Lokesh Kumar Jat, in PGPR Amelioration in Sustainable Agriculture, 2019)

Mao. X., HU. F., Griffiths. B. S., Li. H.,(2006). Bacterial-feeding nematodes enhance root growth of tomato seedlings. Soil Biology and Biochemistry 38(7):1615-1622 DOI:10.1016/j.soilbio.2005.12.002

Maitra.et.al. (2021): Phosphorus fertilization rather than nitrogen fertilization, growing season and plant successional stage structures arbuscular mycorrhizal fungal community in a subtropical forest, *Biology and Fertility of Soils* . 57, 685–697.

Mendes *et. al. 2013*, The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms *FEMS Microbiology Reviews*, 37(5), 634–663. Retrieved from: https://doi.org/10.1111/1574-6976.12028

Mishra, Smita and Susanta S. Chaudhury 2010. Landraces of rice: traditional and participatory conservation system in Jeypore tract of Orissa, pp. 557-585. In: S.D.Sharma (ed), Genetic Resources of Rice in India. Today and Tomorrow's Printers &Publishers. New Delhi.

Mendes, R., Kruijt, M., de Bruijn, I., Dekkers, E., van der Voort, M., Schneider, J. H. M., et al. (2011). Deciphering the rhizosphere microbiome for disease-suppressive bacteria. Science 332, 1097–1100. doi: 10.1126/science.1203980McInerney et al., 2008

Mohammadi K ., Khalesro. S., Sohrabi. Y., Heidari. G.,2011. A Review: Beneficial Effects of the Mycorrhizal Fungi for Plant Growth. Journal of Applied Environmental and Biological Science. 1(9). 310-319.

Nihorimbere, V., Ongena, M., Smargiassi, M., and Thonart, P. (2011). Beneficial effect of the rhizosphere microbial community for plant growth and health. Biotechnol. Agron. Soc. Environ. 15, 327–337.

Nahar K, Kyndt T, De Vleesschauwer D, Höfte M, Gheysen G. (2011). The jasmonate pathway is a key player in systemically induced defence against root knot nematodes in rice. *PlantPhysiology*, 157, 305–316

Nahar K, Kyndt T, Hause B, Höfte M, Gheysen G. (2013). Brassinosteroids suppress rice defense against rootknot nematodes through antagonism with the jasmonate pathway. *Molecular Plant Microbe Interaction*, 26, 106–115.

Ordookhani, K., K. Khavazi., A. Moezzi and F.Rejali, 2010. Influence of PGPR and AMF onantioxidant activity, lycopene and potassiumcontents in tomato. African Journal ofAgricultural Research, 5(10): 1108-1116.

Patra, B. C. 2000. Collection and characterization of rice genetic resources from Keonjhar district of Orissa. Oryza. 34:324-326.

Pii. Y., Mimmo. T., Tomasi. N., Terzano. R., Cesco. S., Crechio. C., (2015). Microbial interactions in the rhizosphere: beneficial influences of plant growth-promoting rhizobacteria on nutrient acquisition process. A review: *Biology and Fertility of Soils* 51, 403–415

Patra, B.C. and S.R. Dhua 2010. Rice germplasm at Central Rice Research Institute:exploration, collection, conservation and utilisation, pp. 47-77. In: S.D. Sharma (ed),Genetic Resources of Rice in India. Today and Tomorrow's Printers & Publishers.New Delhi

Prasad J S, Vijayakumar C H M, Sankar M, Varaprasad K.S., Srinivasa P M, Kondala R Y. (2006). Root-knot nematode resistance in advanced back cross populations of rice developed for water stress conditions. *Nematologia Mediterranea*, 34, 3–8

Priyadharsini. P., Muthukumar.T., 2016. Interactions Between Arbuscular Mycorrhizal Fungi and Potassium-Solubilizing Microorganisms on Agricultural Productivity. https://link.springer.com/book/10.1007/978-81-322-2776-2

Perotto. S.,Girlanda. M.,Martino. E.,2002. Ericoid mycorrhizal fungi: Some new perspectives on old acquaintances. Plant and Soil 244(1):41-53 DOI:10.1023/A:1020289401610

Poveda (2020). Biological Control of Plant-Parasitic Nematodes by Filamentous Fungi Inducers of Resistance: *Trichoderma*, Mycorrhizal and Endophytic Fungi. REVIEW article*Front. Microbiol*. *Sec. Plant Pathogen Interactions.* Retrieved from: https://doi.org/10.3389/fmicb.2020.00992

Parniske, M. (2008). Arbuscular mycorrhiza: the mother of plant root endosymbioses. *Nat. Rev. Microbiol.* 6, 763–775. Retrieved from: doi: 10.1038/nrmicro1987

Philippot, L., Raaijmakers, J. M., Lemanceau, P., and van der Putten, W. H. (2013). Going back to the roots: the microbial ecology of the rhizosphere. Nat. Rev. Microbiol. 11, 789–799. doi: 10.1038/nrmicro3109

Ren, G., Zhang, H., Lin, X., Zhu, J., and Jia, Z. (2014). Response of phyllosphere bacterial communities to elevated CO2 during rice growing season. Appl. Microbiol. Biotechnol. 98, 9459–9471. doi: 10.1007/s00253-014-5915-0

Ramakrishnan, B., Lueders, T., Dun, P. F., Conrad, R., and Friedrich, M. W. (2001). Archaeal community structures in rice soils from different geographical regions before and after initiation of methane production. FEMS Microbiol. Ecol. 37, 175–186. doi: 10.1111/j.1574-6941. 2001.tb00865.x

Rillig, M. C. (2004). Arbuscular mycorrhizae, glomalin, and soil aggregation. *Can. J. Soil Sci.* 84, 355–363. doi: 10.4141/S04-003

Remy. W., Taylor. T. N., Hass. H., 1994. 400-million-year-old vesicular arbuscular mycorrhizae (VAM). 4. Proceedings of the National Academy of Sciences 91(25):11841-3. DOI:10.1073/pnas.91.25.11841

Redecker.D., Kodner. R., Graham. L. E.,2000. Glomalean fungi from the Ordovician. Science. 15;289(5486):1920-1. doi: 10.1126/science.289.5486.1920

Read, D. J., Duckett, J. G., Francis, R., Ligrone, R., and Russell, A. (2000). Symbiotic fungal associations in 'lower' land plants. Philos. Trans. R. Soc. Lond. Ser. B-Biol. Sci. 355, 815–830. doi: 10.1098/rstb.2000.0617

Rillig. C. M., Mummey.D.L., 2006. Mycorrhizas and soil structure. New PhytologistVolume 171, Issue 1 p. 41-53. https://doi.org/10.1111/j.1469-8137.2006.01750.x

Sandhu, J. S. (2014). Status Paper on Rice. *Directorate of Rice Development, Govt. of India, ministry of agriculture, Patna* (*Bihar*), 151

Sinha, A. K. and Mishra, P. K. 2013. Agromorphological characterization and morphology Based Genetic Diversity Analysis of Landraces of rice variety (Oryza sativa L.) of Bankura district of West Bengal. International Journal of Current Research, 5(10):2764-2769.

Sinha, A. K. and Mishra, P. K. 2013. Morphology based multivariate analysis of phenotypic diversity of landraces of rice (Oryza sativa L.) of Bankura district of West Bengal. Journal of Crop and Weed, 9(2):115-121.

Sinha, A. K. and Mishra, P. K. 2014. Rice diversity and sustainable agriculture of lateritic region of West Bengal (India). Biodiversity and Livelihood: Proc. Nat. Conf. Biod., 293-297.

Sinha, A. K. and Mishra, P. K. 2015. Grain morphological diversity of traditional rice varieties (Oryza sativa L.) inlateritic region of West Bengal. International Journal of Conservation Science, 6(3):419-426.

Sinha, A. K. and Mishra, P. K. 2015. Identification of genetically distant rice genotypes for selection-based crop improvement from rice landraces of red and lateritic regionof West Bengal through cluster analysis. American Eurasian J. Agric. & Environ. Sci, 15 (3): 411-414.

Sinha, A. K. and Mishra, P. K. 2015. Identification of important agro-morphic characters of traditional rice (Oryza sativa L.) of West Bengal for crop improvement through principal component analysis. The Ecoscan, 9(1&2):541-546.

Sinha, A. K. and Mishra, P. K. 2015. Rice Biodiversity and Sustainable Agriculture of Lateritic Region of West Bengal (India), on "Biodiversity and Crop Improvement" edited by Shabir H Wani, Scientific Research Publishing, Inc, USA,pp: 221-292.

Sinha, A. K. and Mishra,P. K. 2013. Agro-morphological characterization of rice landraces variety (Oryza sative L.) of Bankura district of West Bengal. Research in Plant Biology, 3(5):28-36.

Subudh. H. N., Dash.SK., Meher. J., Mohapatra. S., Mishra. CD. (2017). Evaluation of rice varieties for rice Root knot Nematode (*Meloidogyne graminicola*). *Journal of Entamology and Zoology Studies*,5(5): 1213-1215.

Soriano.I. R., Schmit. V., Darsan. S. B.1999. Resistance to rice root-knot nematode Meloidogyne graminicola identified in Oryza longistaminata and O. glaberrima. Nematology. 1(4). 395-398. DOI: https://doi.org/10.1163/156854199508397

Sharma-Poudyal D, Pokharel R, Shrestha S M, Khatri-Chhetri G B. (2004). Evaluation of common Nepalese rice cultivars against rice root knot nematode. *Nepal Agriculture Research Journal*, 5, 33–36.

Smith. F. A., Graham. J. H., Jounson. N.C.,1997. Functioning of mycorrhizal associations along the mutualism–parasitism continuum. The New Phytologist. Cambridge University press.135(4)

Simon. L., Bousquet. J., Levesque. R.C., Lalonde. M.1993. Origin and diversification of endomycorrhizal fungi and coincidence with vascular land plants. *Nature* volume 363,67–69.

SchüBler. A.,Schwarzott. D.,Walker, 2000. A new fungal phylum, the *Glomeromycota*: phylogeny and evolution. Mycologhical Research. 105 (12). 1413-1421.

Smith, S. E., and Read, D. J. (2010). Mycorrhizal Symbiosis. 3rd Edn. New York, NY: Academic Press.

Schouteden, (2015). Arbuscular Mycorrhizal Fungi for the Biocontrol of Plant-Parasitic *Nematodes: A Review of the Mechanisms Involved;*

Su H., Zhao Y., Zhou J., Feng H., Jiang D., Zhang K.Q., Yang J. (2017). Trapping devices of nematode-trapping fungi: Formation, evolution, and genomic perspectives. *Biol. Rev.;* 92:357–368.

Sankaranarayanan, C.; Hari, K. 2021. Integration of Arbuscular Mycorrhizal and Nematode Antagonistic Fungi for the Biocontrol of Root Lesion Nematode Pratylenchus zeae Graham, 1951 on Sugarcane. FAO. AGRIS. 1(168).194-200.

Tisdale, S.L.; Nelson, W.L. and Beaton, J.D. (1995). *Soil Fertility and Fertilizers*. The Macmillan, New York.

Tripathi, S., Kamal, S., Sheramati, I., Oelmuller, R., (2008). Book: *Mycorrhiza*. Edition: 2008. Chapter: Mycorrhizal Fungi and Other Root Endophytes as Biocontrol Agents Against Root Pathogens. Publisher: Springer-Verlag Berlin Heidelberg. Editors: A. Varma. 281-307.

Torr. P., Spiridonov. S.E., Heritage. S., Wilson. M. J.,2007. Habitat Associations of Two Entomopathogenic Nematodes: A Quantitative Study Using Real-Time Quantitative Polymerase Chain Reactions. Journal of Animal EcologyVol. 76, No. 2 (Mar., 2007). 238-245. https://www.jstor.org/stable/4539124

Tagu D and Barker S J 1997 At the root of mycorrhizal symbioses. Trends Plant Sci. 2, 2-3.Tunlid, (199l). Surface polymers of the nematode-trapping fungus Arthrobotrys oligospora Printed in Great Britain, *Journal of General Microbiology* 137, 1231-1240

van der Heijden, M. G. A., Klironomos, J. N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., et al. (1998). Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature* 396, 69–72. doi: 10.1038/23932

van der Heijden, M. G. A., and Horton, T. R. (2009). Socialism in soil? The importance of mycorrhizal fungal networks for facilitation in natural ecosystems. *J. Ecol.* 97, 1139–1150. doi: 10.1111/j.1365-2745.2009.01570.x

van der Heijden, M. G. A., Martin, F. M., Selosse, M. A., and Sanders, I. R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytol.* 205, 1406–1423. doi: 10.1111/nph.13288

van der Heijden, M. G. A., Bardgett, R. D., and van Straalen, N. M. (2008). The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol. Lett. 11, 296–310. doi: 10.1111/j.1461-0248.2007.01139.x

Wu, W. X., Liu, W., Lu, H. H., Chen, Y. X., Medha, D., and Janice, T. (2009). Use of 13C labeling to assess carbon partitioning in transgenic and nontransgenic (parental) rice and their rhizosphere soil microbial communities. FEMS Microbiol. Ecol. 67, 93–102. doi: 10.1111/j.1574-6941.2008.00599.x

Wang, B., and Qiu, Y. L. (2006). Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza* 16, 299–363. doi: 10.1007/s00572-005-0033-6

Welbaum, G. E., Sturz, A. V., Dong, Z., and Nowak, J. (2004). Managing soil microorganisms to improve productivity of agro-ecosystems. *CRC. Crit. Rev. Plant Sci.* 23, 175–193. doi: 10.1080/07352680490433295

Wang (2018). Rice Secondary Metabolites: Structures, Roles, Biosynthesis, and Metabolic Regulation. *Molecules.* 23(12): 3098. Retrieved from: doi: 10.3390/molecules23123098 -

Watanabe, A., Takeda, T., and Kimura, M. (1999). Evaluation of origins of CH4 carbon emitted from rice paddies. J. Geophys. Res. 104, 23623–23629. doi: 10.1029/1999JD900467

Yang, J., Kloepper, J. W., and Ryu, C.-M. (2009). Rhizosphere bacteria help plants tolerate abiotic stress. Trends Plant Sci. 14, 1–4. doi: 10.1016/j.tplants.2008.10.004Whipps, J. M. (2004). Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Can. J. Bot.* 1227, 1198–1227. Retrieved from: doi: 10.1139/B04-082

Yeates. G. W. (1993). Feeding Habits in Soil Nematode Families and Genera--An Outline for Soil Ecologists. *Journal of Nematology* 25(3):315-331.

Yen-Ping Hsueh.(2017). Nematophagous fungus *Arthrobotrys oligospora* mimics olfactory cues of sex and food to lure its nematode prey e20023. *eLife.* ; 6: Retrieved from: doi: 10.7554/eLife.20023

Yeates, G.W. (2003). Nematodes as soil indicators: functional and biodiversity aspects. Biology and Fertility of Soils, 37(4), pp. 199–210. doi:10.1007/s00374-003- 0586-5.

Zhu, X.C., F.B. Song FB and H.W. Xu, 2010. Arbuscular mycorrhizae improve low temperature stress in maize via alterations in host water status and photosynthesis. Plant Soil., 331: 129-137.

Zhang, Y., Shuoshuo, L., Ruirui, W., Zhang, K. Q., Jianping X. (2020). Fungi- Nematode Interactions: Diversity, Ecology, and Biocontrol Prospects in Agriculture. *Journal of Fungi.* 6(4): 206. Retrieved from: doi: 10.3390/jof6040206