AM Biofertilizer And Sustainable Resource Management For Arid Land Cultivation Practice

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Abstract- *Arbuscular mycorrhiza (AM) plays a crucial role to combat the water stress condition in dry land for the host plants. More than 80% of the angiosperm plants are AM infected symbiotically. So, the use is beneficial and application is very crucial as biofertlizers. In this communication broad aspects of AM use pattern and its global perspective have been presented. Result revealed that natural forest with AM spore density affect positively on geophyte yield.*

Keywords: AM, biofertilizers, agricultural yield, arid forestry, management.

I. INTRODUCTION

Our climate is governed by the natural activities imposed in the ecosystem. So the forces are governing by the nature in general. Climate change is fundamentally reshaping the conditions under which agriculture is planned, designed, and operated. This led to change of yield though we are trying to cope the harsh environment by techniques and tools developed by scientist and experts time to time. Rising temperatures, shifting precipitation regimes, intensifying extremes like heatwaves, droughts, floods even sea-level rise, and growing climatic variability are altering both water supply and demand. These stressing agricultural structures and irrigation systems which have largely designed under stationary climate assumptions. This confluence raises urgent questions about how to adapt irrigation technologies, storage and conveyance networks, and on-farm structures. Examples are based on the designed structures like greenhouses, postharvest facilities, livestock housing etc. to ensure productivity, safety, and resilience through mid-century and beyond.

We see many phenomena that are originated over the past decade, multiple lines of evidence have converged on several robust signals. First, warming is increasing atmospheric evaporative demand, often outpacing precipitation gains even in regions projected to become wetter, thereby tightening water budgets for crops and ecosystems (Cook *et al*., 2023a,b,c,d,e,f; Vicente-Serrano *et al*., 2023). Second, precipitation variability is increasing, with a higher frequency and intensity of heavy rainfall events alongside longer dry spells—a duality that challenges both drainage and storage design criteria (Myhre *et al*., 2019; IPCC, 2023). Third, extremes are rising in magnitude and clustering, compounding multi-hazard risks to structures and operations, such as concurrent heat and drought episodes or storm–surge–flood combinations that disrupt power, damage assets, and degrade water quality (Raymond *et al*., 2020; Kopp *et al*., 2023). Fourth, water competition across sectors is intensifying, especially during drought, highlighting governance, allocation, and market mechanisms as central to infrastructure performance and equity outcomes (Grafton *et al*., 2023; FAO, 2023).

Within this context, irrigation systems face both rising demand and greater supply uncertainty. Elevated temperatures and vapor pressure deficits increase reference evapotranspiration (ETo), raising peak-season water requirements even where CO_2 fertilization may slightly improve water-use efficiency at leaf scale (Allen *et al*., 2022; Deines *et al*., 2022). At farm and basin scales, these effects interact with crop choices, planting calendars, soil attributes, and water rights to reshape seasonal demand profiles (Bastiaanssen& Allen, 2021). Supply reliability is further strained by snowpack decline, earlier runoff, groundwater depletion in stressed aquifers, and salinity intrusion in coastal deltas (Huss & Hock, 2018; Jasechko*et al*., 2021; Hossain *et al*., 2022). Together, these dynamics necessitate both hardware adaptation-more flexible, efficient, and robust delivery systems—and software adaptation-sensing, forecasting, scheduling, and policy innovations.

Climate change raises design loads and operational thresholds for agricultural structures. Heatwaves increase cooling loads for livestock housing and greenhouses, requiring redesigned ventilation, shading, evaporative cooling, and thermal storage strategies to prevent productivity losses and mortality (Both *et al*., 2022; Renaudeau*et al*., 2022). Intense precipitation and wind events test cladding, anchoring, and drainage, while hail and wildfire smoke pose emerging threats to protected cultivation and postharvest facilities

(Abatzoglou*et al*., 2021; Yuan *et al*., 2021). In many regions, flood frequency analyses based on stationary statistics underestimate future risks, motivating adaptive design standards that incorporate non-stationarity and compound hazards (Milly *et al*., 2015; Slater *et al*., 2021). Additionally, power reliability during extremes has become a critical dependency; distributed energy and storage can provide resilience for pumps, cooling, and control systems (Gielen *et al*., 2023a,b).

Technological innovation is rapidly reframing adaptation options. On the irrigation side, precision application (e.g., variable-rate irrigation, subsurface drip), deficit and regulated deficit irrigation, deficit-tolerant cultivars, and soil–plant–atmosphere monitoring are increasingly integrated with forecast-driven scheduling and decision-support tools (Friedrichs *et al*., 2023a; Pagay *et al*., 2022). At the conveyance and storage level, managed aquifer recharge (MAR), aquifer storage and recovery (ASR), conjunctive use, and nature-based retention (e.g., floodplain reconnection, farm ponds, and small reservoirs) can buffer variability while providing co-benefits such as groundwater replenishment and habitat (Dillon *et al*., 2020; Harrison *et al*., 2022). For structures, passive design (orientation, insulation, thermal mass), reflective and phase-change materials, adaptive shading, and high-efficiency heat pumps are being combined with advanced controls to keep internal climates within biological setpoints under wider ambient ranges (Körner & Both, 2023).

Despite progress, three gaps persist. First, scaling: many innovations demonstrate promise in pilots but require integration into basin governance, finance, and supply chains to deliver system-level benefits (Wheeler *et al*., 2020a,b; Grafton *et al*., 2023). Second, metrics: commonly used performance indicators often exclude resilience attributes such as recovery time, fault tolerance, and service continuity under stress; moving toward resilience-informed and lifecycle-cost accounting is needed (Aven, 2016; Linkov & Trump, 2019). Third, uncertainty: decision-making must embrace deep uncertainty in climate trajectories and socio-economic futures; robust decision making (RDM), dynamic adaptive policy pathways (DAPP), and real options are increasingly applied to agricultural water and infrastructure planning (Haasnoot*et al*., 2013; Lempert *et al*., 2022).

This chapter situates agricultural structures and irrigation within these evolving risk landscapes and solution spaces. It synthesizes biophysical drivers affecting loads and water balances; assesses implications for engineering design, operation, and maintenance; reviews advance in sensing, modelling, and decision-support; and discusses policy, institutional, and financial architectures that enable resilient adaptation. Throughout, we emphasize translating climate science to actionable criteria—e.g., updating design storms, wind and snow loads, heat stress thresholds, seepage allowances, conveyance freeboard, and water allocation rules- while highlighting co-benefits such as energy efficiency, carbon reduction, biodiversityandlabour safety. Case studies illustrate context-specific adaptation pathways across arid/semi-arid irrigation districts, monsoonal basins, coastal deltas, and temperate protected-cropping regions. The goal is pragmatic, equip practitioners and policymakers with evidence-based frameworks to retrofit existing systems and build new infrastructure that can thrive under nonstationary climates. Under these circumstances scientists use arbuscular mycorrhizal (AM) biofertilizers to mitigate the process and to hold the large-scale production of crops even to protect the soil for rapid restoration if degraded earlier.

II. RATIONALE OF THE STUDY

The study on AM is essential because the fungal biofertilizer and sustainable resource management is interlinked for arid land cultivation practice is in general has the multiracial reasons. These are to addressing Food Security. As per the report it is revealed that arid lands cover approximately 40% of the Earth's land surface, and their cultivation is essential for ensuring global food security. However, these regions face severe water scarcity, poor soil health, and limited agricultural productivity. By and large many counties face the threat during arid zone cultivation and they use the Am fertilizer for better understanding. It also associated with environmental concerns. Conventional agricultural practices in arid lands often lead to soil degradation, water pollution, and loss of biodiversity. There is a pressing need for sustainable and eco-friendly approaches to manage these fragile ecosystems. So, environment friendly cultivation is used everywhere to face the multiracial problems. The AM is a potential biofertilizer based on fungi. AM fungi have been recognized as a promising biofertilizer, enhancing plant growth, improving soil structure, and increasing water use efficiency even support plant yield in a protective way. Their application can reduce the reliance on chemical fertilizers and pesticides, mitigating environmental risks. So, to generate the soil health and productivity large scale AM fertilizers have been used widely. Last but not least one is the sustainable resource management. It aims to develop and promote sustainable resource management practices, including the use of AM biofertilizer, to improve soil health, conserve water, and enhance crop productivity in arid lands. Additionally, AM helps to mitigate the climate change environmental stress on crops. So, techniques have been adopting sustainable agricultural practices, farmers in arid lands can contribute to climate change mitigation by sequestering carbon, reducing greenhouse gas emissions, and promoting ecosystem resilience. The use of AM in the community stands for economic yield. The so-called economic benefits concerned with it. The future outcomes can benefit small-scale farmers in arid regions, improving their livelihoods, increasing crop yields, and enhancing food security. It helps to develop policy for large scale economic rotation and good potential yield in various Agri-horticultural sectors.Research findings can inform policy decisions on sustainable agriculture, environmental conservation, and rural development in arid regions. Outside the arid zone it widely forecasts same production type on the basis of soil health even cope the soilborne pathogens that are negatively linked with economic growth of valued crops. It has its many objectives in the ecosystem for large scale use of AM biofertilizers. It reflects the idea to evaluate the efficacy of AM biofertilizer in improving crop productivity and soil health in arid lands. To develop and promote sustainable resource management practices for arid land cultivation and their proper use through global technology at local sites. To assess the economic and environmental benefits of AM biofertilizer application. Last but not least to contribute to policy discussions on sustainable agriculture and environmental conservation in arid regions. Through the use of Am culture many outcomes may develop. These are improved crop productivity and soil health in arid lands, reduced reliance on chemical fertilizers and pesticides with the advent of time. Enhanced water use efficiency and conservation even increased adoption of sustainable resource management practices by farmers. The policy recommendations for sustainable agriculture and environmental conservation in arid regions as per the need.

Studies revealed that there are many reports on AM association with plants from various parts of the globe (Basu and Srivastava, 1998; Panwarand Tarafdar, 2006; Arpana and Bagyaraj, 2007; Gupta *et al.*, 2009; Ram and Bhadauria, 2009; Zubek and Blaszkowski, 2009; Gupta *et al*., 2000; Mir Hassan *et al,* 2010; Hemashenpagam, 2010; Gaur and Kausik, 2011b; Sing and Vyas, 2011; Koul, *et al*., 2012; Zubek *et al*., 2013; Paul and Jayashree, 2014; Muthuraj *et al*., 2014; Das, 2015). Associated AM fungus with the plants not only enhances the growth of the plants but also improves the active constituents of plants reported by many researchers time to time (Basu and Srivastava, 1998; Zubek and Blaszkowski, 2009; Ratti and Upadhyay, 2010; Sing and Vyas, 2011). The production of secondary metabolites is also reported as per the activity of AM fungi on plants (Selvaraj *et al*., 2008). AM fungi have been found to increase chlorophyll content as reported by Demir (2004), Karthikeyan *et al*., (2009), Ghosh, (2017). The effect of AMF in the plant-soil system has been studied by Ying Wu Shi et al. (2026). They stated that future research should focus on the interaction mechanisms between AMF and plants and the optimization of its application technology, so as to give full play to its potential in every sphere of agriculture. Hence, there is a need of research in improving the quality and quantity of plant produce or yield in terms of biomass production from native crop plants in relatively shorter period and at lower expense using VAM fungi at dry lateritic belt of West Bengal.

A part of Southwest Bengal has lateritic dry areas and water scarcity is a major problem. Cultivation of crops in such areas is very problematic so need special attention on such stress prone condition. High temperature and low water retaining capacity hampers the growth of the plant and cultivation is under challenge. However, no attempt has been made to study the mycorrhizal status and their effect on the growth and survival of the medicinal plants of Southwest Bengal. Therefore, the present study has been conducted to understand the actual scenario of AM status of some crop plants in Southwest Bengal with special emphasis to crop yield under dry land situation.

The acidic and lateritic soil of Southwest Bengal is characterized by low P^H range between 5.4 -6.5 (Sengupta *et al*., 2001). As per the report of Ghosh and Verma (2002) iron and aluminum rich lateritic soil of Southwest Bengal is characterized by low P^H where phosphorus is fixed causing deficiency and the total phosphorus (P) is 0.048 percent and available phosphorus only 0.002 percent. Leaching renders the soil poor in nutrients. The survival of plants in such a harsh condition is more mycorrhizae dependent than the normal soil because, mycorrhizal activity is augmented in nutrient poor soil (Mosse, 1973, Ghosh, 20017). Therefore, incorporation of VAM inoculums in cultural medium is very much essential to enhance the different parameters for better growth and nourishment of plants before planting in any harsh condition.

III. AREA UNDER STUDY

Southwest Bengal in India is a vast tract with different lateritic areas recorded in the districts like Bankura, Jhargram, Paschim Medinipur, Purulia, Birbhum and Burdwan. But for study and survey, only four districts like Bankura, Jhargram, Paschim Medinipur and Purulia were considered because these four districts are adjacent districts with more or less homogeneity of soil type under lateritic category. Another approach is that it is very easy to monitor for successive two-three years. In the present study, more than 120 plant samples and respective rhizosphere soils were collected for study from four study sites. Three sub-types in each area were taken in to consideration and spore density was studies under each type. Inoculum production has been prepared as per standard method and sudan grass was used. Yield was calculated as per the study for optimal growth of species at controlled and inoculated condition at different day intervals.

IV. MATERIALS AND METHODS

Soil sample with intact root systems from rhizosphere was collected around plant species in field from 4 districts seasonally. It was monsoon, winter followed by summer. Each sample was collected in polythene bags and then carried to laboratory seasonally for consecutive two years i.e. 2023-2024 & 2024-2025. The collected soil samples were air dried and assessed for AM spore density study. AM percentage infection in root was assessed as colonization % as perslide method (McGonigle*et al*. 1990)and spores were extracted by wet sieving and decanting method (Gerdemann and Nicolson, 1963). Counting of spores was done under stereomicroscope at Ecology Lab. of GGDC Lalgarh, Jhargram. Growth experiments with the selected mango ginger plant was carried out at the Departmental corridor during late summer to late monsoon. AMF inoculation using AM inocula was done.

Root Colonization study:

Species wise fine feeder roots of the medicinal plants were collected and cut into approx. 1cm pieces. Fragments were washed under tap water properly. Root samples were taken into labeled glass test tubes and 20% potassium hydroxide (KOH) solution added to them so that samples were immersed into the solution properly. The test tubes were kept in the laboratory for three days. The cold treatment is though time consuming at the same time labor saving and easy (Utobo, *et al*., 2011, Zubek *et al*., 2013, Ghosh, 2014). After three days roots were taken in nylon tea-sieves and washed under tap water. Then these pieces were soaked in dilute HCl solutions (1%) for 3-4 minutes and again washed in tap water. Cleared root segments were stained by writing ink (Camel, Royal Blue) as a stain. The samples with stain were kept in the same condition for at least 30 minutes prior observation after rinsing with acidified water. Pigmented root segments after cold treatment were immediately placed in freshly prepared alkaline hydrogen peroxide (H_2O_2) solution at room temperature for 10 to 20 minutes or until roots are bleached (Utobo, *et al*., 2011).

Percent of root colonization = Number of root segments colonized/Number of root segments observed x 100

AMF spore separation and density calculation:

Separation of AM mycorrhizal spores from each plant rhizosphere soil sample was done by using wet sieving and decanting method (Gerdemann and Nicolson, 1963). From each stock soil sample, 100 g soil was taken and mixed with 1 liter normal tap water in large beaker and stirred by glass rod until all the aggregates dispersed to leave a uniform suspension. The suspension was passed through stack of sieves, 780 µm, 150 µm, 75 µm, 53 µm and 32 µm consecutively for several time repeats. The residues of respective sieves were collected in separate beaker. Then the aliquots were passed through filter paper placed in a glass funnel. To accumulate spores in a single circle clear water drops should be tickled through dropper. Now the filter papers were placed in wet Petri dish and spores were counted and observed through stereomicroscope (×40). Total spores were counted by adding the spore numbers of each respective filter paper spore numbers. Spore density was calculated by counting the spores in the 100 g of soil. Spores were separated by wooden dowel and mounted in lacto phenol for temporary work. Permanent slides were prepared for further work and spores were mounted in Polyvinyl-alcohol-lacto-glycerol (Koske and Tessier, 1983).

Collected soil samples from field was carried out in to the laboratory and used for mango ginger cultivation. One soil as sterilized one has been taken in to account as control and other 3 were used as experimental pots. In total 3 control and 12 experimental polypots were placed for study. Each polypot having 2kg soil (specific) and approx. of 10g of rhizome of mango ginger was used in each polypots. Growth parameters were recorded though ultimately after 5 months rhizome of each pot was collected and studied for biomass estimation.

V. RESULTS AND DISCUSSION

In the monsoon period (May-July) highest spore density was observed during monsoon in case of *Elephantopusscaber*L. (144.6±8.05) in the year 2023-2024 followed by *Phyllanthus amarus*Schum & Thonn. (131.3±8.3) and the lowest in case of *Carissa spinarum*L. (18±8.0). Five species showed more than 100 spore number during monsoon at the same site duringstudy (Table 2).In the successive year, highest number of spore density was observed in *Phyllanthus amarus*Schum &Thonn.(122±17.3) and lowest spore density in case of *Carissa spinarum*L. (18.3±2).

In the winter, the highest number of spore density was observed in case of *Aristolochia indica* L.(352.6±3.5)followed by *Costus speciosus* (Koenig ex Retz.) J.E.Smith (312±5.09) and the lowest in *Chrysopogonaciculatus* (Retz.) Trin. (41±4.3). In the following year the highest spore population i.e. 352.6±1.8 was recorded by *Aristolochia indica* L. (354.6±1.8) and lowest by *Chrysopogonaciculatus* (Retz.) Trin. (40±1.6).

In summer, highest spore density in the year 2023-2024 was recorded in case of *Aristolochia indica* L. (212.6±6.6) followed by *Costus speciosus* (Koenig ex Retz.) J. E. Smith (171.6±4.7) and lowest in *Chrysopogonaciculatus* (Retz.) Trin. (17.6±2.05).

In the next year, the highest to lowest spore number during summer was recorded in case of shrubby species. *Aristolochia indica* L. was unique to show maximum spore number in three consecutive seasons. The range of spore density in the consecutive years was 352.6±3.5 to 18±8.0 per 100grhizospheric soil (Table 2).

So, result revealed that there is a uniqueness of spore density at forest soil which was undisturbed and that might be a good reservoir for spore culture before inoculums production.

In the forest more than 36 different medicinal plant species studied under 21 different families. Plants under the family Fabaceae showed highest species diversity (seven species) where colonization percentage ranged between 98±0.8 (*Flemingiastrobilifera* (L.) R. Br.) to 19.3±0.4 (*Indigofera cassioides* Rott. *ex* DC.) in both the years (Table 1). Rhizospheric soil around these species may be a good source for spore isolation from forest soil. Spores available here are *Glomus, Gigaspora, Scuttelospora* and *Acaulospora* sp. (Fig. 3). In general soil mix with different AM spores along with other soil microorganisms.

Spore density varies from site to site, from season to seasons and under different management strategies. Result revealed that forest soil is a good repository of AM spores (415/100g) while other soils from agricultural sites showed less to lesser number of AM spores i.e. garden soil with 280/100g and agricultural soil with 180/100g (Table 3). The degraded land soil with pebbles and with scattered vegetation showed 40 AMF spore per 100g rhizosphere soil (Fig. 2).

Table 1: AM colonization status of selected plants of forests in Southwest Bengal

SlNo.	Scientific Name of the selected medicinal plants	Season wise root colonization percentage (R- rainy, W-Winter,S-Summer) 2023-2024			Season wise root colonization percentage (R- rainy, W-Winter,S-Summer) 2024-2025		
		Rainy/Monsoon (Mean of 3)	Winter (Mean of 3)	Summer (Mean of 3)	Rainy/Monsoon (Mean of 3)	Winter (Mean of 3)	Summer (Mean of 3)
1.	*Allophylluscobbe*(L.) Reausch.	48.3±1.2^{j-l}	30.6±2.4^{i-l}	17±2.1^{g-i}	46.6±1.2^{h}	34.3±0.8^{g-k}	17.3±0.4^{f-i}
2.	*Andrographis paniculata* (Burm.f.)Wall.ex Nees.	61.3±3.3^{g-j}	18.3±1.2^{l-n}	10±1.6^{h-j}	59.6±1.2^{f-h}	40±0.8^{g-i}	10.5±0.9^{h-j}
3.	*Antidesmaghaesembilla*Gaertn.	54±3.2^{i-l}	27.3±5.2^{j-m}	16±1.6^{g-i}	50±1.2^{f-h}	21.3±1.8^{j-m}	16±0.8^{g-i}
4.	*Aristolochia indica* L.	98±0.8^{a}	88.3±2.05^{a}	47.3±2.05^{ab}	97.3±0.4^{a}	85.3±4.4^{a}	46±0.8^{ab}
5.	*Bonnayabrachiata* Link. & Otto.	81.3±2.4^{b-f}	PNV	PNV	78.3±1.2^{b-d}	PNV	PNV
6.	*Botrychium doucifolium* Wall. ex Hooker & Grev.	Nil	Nil	Nil	Nil	Nil	Nil
7.	*Carissa spinarum*L.	14.6±4.1^{m-o}	Nil	Nil	13.6±.2ij	Nil	Nil
8.	*Chrysopogonaciculatus* (Retz.) Trin.	11±0.8^{no}	Nil	PNV	10±0.8^{i}	Nil	PNV
9.	*Clerodendrum viscosum*Vent.	92±2.1^{a-e}	91±0.8^{a}	53±2.1^{a}	92.3±2.05^{ab}	63±2.1^{bc}	51±2.1^{a}
10.	*Clerodendrum indicum* (L.) O. Ktze.	84.6±1.24^{a-f}	62±1.6^{b-e}	44.3±1.2^{a-c}	81±0.8^{bc}	41.3±2.4^{g-i}	36.3±1.2^{b-e}
11.	*Commelinaobliqua*Vahl.	56.6±2.4^{g-k}	48.3±1.24^{e-h}	23.3±1.24^{e-h}	52±2.16^{f-h}	45±2.16^{f-h}	23.3±1.69^{e-h}
12.	*Costus speciosus* (Koenig ex Retz.) J.E. Smith	96±2.1^{ab}	64.8±8.0^{b-d}	PNV	92.3±2.05^{ab}	60.3±2.05^{b-e}	PNV
13.	*Curculigoorchioides*Gaertn.	70±3.2^{fg}	43.6±2.6^{f-i}	PNV	63.3±2.4^{ef}	PNV	PNV
14.	*Cyperus kyllinga*Endl.	22±1.6^{mn}	15.3±2.4^{m-o}	12.6±2.0^{h-j}	16±0.8^{i}	Nil	Nil
15.	*Desmodiummotorianum*(Houtt.) Merr.	81.6±1.6^{b-f}	69.3±2.4^{b}	12.3±1.6^{h-j}	64±2.9^{ef}	20±0.8^{j-m}	9.3±0.9^{h-j}
16.	*Desmodiumtriflorum*(L.)DC.	54±2.9^{i-l}	50.3±1.2^{d-g}	42.6±0.9^{a-c}	48±1.6^{gh}	16.6±4^{lm}	11.3±0.9^{h-j}
17.	*Diclipterabupleuroides*Nees.	70.3±2.04^{f-h}	65±3.5^{b-d}	45.3±2.4^{a-c}	65±0.8^{d-f}	62.3±1.2^{b-d}	43.6±1.2^{a-c}
18.	*Dioscorea bulbifera*L.	96±1.6^{ab}	PNV	PNV	91±0.8^{a-c}	PNV	PNV
19.	*Dioscorea pentaphylla* L.	95.3±1.2^{a-d}	PNV	PNV	92±1.6^{ab}	PNV	PNV
20.	*Elephantopusscaber*L.	52±1.6^{i-l}	48.3±1.2^{e-h}	PNV	46.6±1.2^{h}	9.3±0.9^{mn}	PNV
21.	*Evolvulusnummularius*L.	94±1.6^{a-d}	35±0.8^{h-k}	28±1.6^{d-g}	93±2.1^{ab}	34.6±0.4^{g-j}	26.3±1.6^{d-g}
22.	*Flacourtia indica* (Burm.f.) Merr.	40.6±2.4^{l}	15±2.1^{m-o}	10±1.6^{h-j}	81±0.8^{bc}	72.3±2.05^{b}	12±1.6^{g-j}
23.	*Flemingiachappar*Buch.-Ham. ex Benth.	55±4.08^{h-l}	30±0.8^{i-l}	PNV	56.6±1.2^{f-h}	40.3±1.2^{g-i}	PNV
24.	*Flemingiastrobilifera* (L.) R. Br.	98±0.8^{a}	59.6±2.0^{b-e}	PNV	93.3±4.02^{ab}	19.6±2.05^{k-m}	PNV
25.	*Gardenia gummifera*L. f./	58.6±1.6^{g-k}	30.3±1.2^{i-l}	11±0.8^{h-j}	53.6±1.2^{f-h}	29±0.8^{i-l}	11±0.8^{h-j}
26.	*Hemidesmus indicus* (L.) R. Br.	43.6±4.4^{k-l}	31±0.8^{i-l}	20.6±0.9^{f-i}	47±2.1^{gh}	39.6±1.2^{g-i}	21±0.8^{f-i}
27.	*Holarrhena pubescens* Wall. ex G. Don.	55±4.08^{h-l}	52.3±2.3^{d-f}	41.6±0.4^{a-d}	53±2.1^{f-h}	48.3±1.2^{d-g}	39±0.8^{a-d}
28.	*Ichnocarpus frutescens* (L.) R. Br.	78.6±2.8^{ef}	40.6±2.4^{f-j}	31.6±1.2^{c-f}	80±1.6^{bc}	57±2.05^{c-f}	31±0.8^{c-f}
29.	*Indigofera cassioides*Rott.*ex* DC.	60.6±3.2^{g-j}	23.3±3.3^{k-n}	20.6±0.9^{f-i}	60±1.6^{f-h}	21±0.8^{j-m}	19.3±0.4^{f-i}
30.	*Meynaspinosa*Roxb.	27.3±1.2^{m}	10.6±0.9^{no}	7±0.8^{ij}	23.6±1.2^{i}	8±0.8^{mn}	7±0.8^{ij}
31.	*Phaseolus adenanthus*G. Mey.	64.3±3.2^{g-i}	50.3±1.2^{d-g}	PNV	62±1.6^{fg}	47.3±1.6^{e-g}	PNV
32.	*Phyllanthus amarus*Schum& Thonn.	92.6±4.4^{a-e}	54.3±1.2^{c-f}	PNV	90.6±0.9^{a-c}	44±0.8^{f-h}	PNV
33.	*Pueraria phaseoloides*(Roxb.) Benth.	81±2.9^{b-f}	69.3±0.9^{b}	36.6±2.4^{b-e}	76.6±1.2^{c-e}	65±0.8^{bc}	35.6±0.4^{b-e}
34.	*Scoparia dulcis* L.	53.3±2.4^{i-l}	67.3±1.2^{bc}	40.6±0.94^{a-d}	51±0.8^{f-h}	62±1.6^{b-d}	39.6±2.05^{a-d}
35.	*Smilax ovalifolia*Roxb. ex D. Don.	60±1.6^{g-j}	33±1.4^{i-l}	PNV	56.3±1.2^{f-h}	31±0.8^{h-l}	PNV
36.	*Vernonia cinerera*Less.	57.6±1.6^{g-k}	36±1.6^{g-k}	12.3±1.8^{h-j}	52.6±2.05^{f-h}	20±0.8^{j-m}	11±0.8^{h-j}

Note: PNV-Plant not visible, NA-Not Applicable, Nil-No infection; DP-Dead Plant, *Holarrhenaantidysenterica* (L.) Wall. *ex* Dc. = Syn. *H.* ***p****ubescens* Wall. ex G. Don. , Each value represents mean of three soil samples. Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by Duncan's Multiple Range Test (DMRT), M-Monsoon, W-Winter, S-Summer. Data was the mean of 4 study sites.

Table 2: AM Fungal spore density in rhizospheric soil of forest at lateritic forests of W.B.

Sl. No.	Scientific Name of the selected medicinal plants	Season wise Spore density in 100 g rhizospheric soil for a year 2023-2024 (R- rainy, W-winter, S-summer)			Season wise Spore density in 100 g rhizospheric soil for a year 2024-2025 (R- rainy, W-winter, S-summer)		
		M	W	S	M	W	S
1.	*Allophylluscobbe*(L.) Reausch.	74.6±15.1^{e-g}	213.3±9.54^{j}	83±9.4^{jk}	61.6±6.2^{f-h}	192.6±8.9^{g-i}	87.3±7.1^{h-j}
2.	*Andrographis paniculata* Nees.	90.6±5.7^{cd}	286.6±4.6^{d}	144.6±5.5^{d}	81.3±6.6^{cd}	262.3±6.1^{bc}	132.6±5.2^{c}
3.	*Antidesmaghaesembilla*Gaertn.	39.6±8.5^{lm}	146.6±4.6^{l}	95.3±4.1^{h-j}	43.6±3.8^{ij}	136±4.3^{op}	96±4.3^{f-i}
4.	*Aristolochia indica* L.	146±6.4^{a}	352.6±3.5^{a}	212.6±6.6^{a}	110.6±8.2^{b}	352.6±1.8^{a}	202.6±5.2^{a}
5.	*Bonnayabrachiata* Link. & Otto.	62±7.4^{g-i}	PNV	PNV	72±8.6^{def}	PNV	PNV
6.	*Botrychium doucifolium* Wall. ex Hooker & Grev.	23.3±2.4^{n}	74.6±4.1^{o}	45±4.08^{n}	21.6±1.24^{k}	70±0.81^{r}	45.3±4.1^{m}
7.	*Carissa spinarum*L.	18±8.0^{n}	28±6.2^{q}	20±4.08^{o}	18.3±2.0^{k}	27.3±2.0^{t}	20.6±0.9^{n}
8.	*Chrysopogonaciculatus* (Retz.) Trin.	22.3±2.0^{n}	41±4.3^{p}	17.6±2.05^{o}	22±2.1^{k}	40±1.6^{s}	PNV
9.	*Clerodendrum viscosum*Vent.	55.6±3.2^{h-k}	212.6±8.5^{j}	113.3±4.9^{fg}	56.6±4.9^{g-i}	197.3±5.4^{f-h}	95.3±4.1^{h-i}
10.	*Clerodendrum indicum* (L.) O. Ktze.	50±1.6^{i-m}	153.3±5.4^{l}	72.6±5.2^{kl}	52±0.8^{g-j}	117±4.9^{q}	78.3±5.9^{jk}
11.	*Commelinaobliqua*Vahl.	70.3±3.6^{f-h}	188.3±6.4^{k}	106.6±4.9^{f-h}	43.3±6.1^{ij}	142.3±6.1^{no}	84.3±6.5^{i-k}
12.	*Costus speciosus* (Koenig ex Retz.) J.E. Smith	112.6±5.2^{b}	312±5.09^{b}	171.6±4.7^{bc}	93±8.0^{c}	233.3±4.7^{d}	PNV
13.	*Curculigoorchioides*Gaertn.	88±6.1^{c-e}	102.6±3.3^{mn}	PNV	64±4.3^{efg}	PNV	PNV
14.	*Cyperus kyllinga*Endl.	37±8.0^{m}	160±4.3^{l}	62.3±7.5^{lm}	37.3±5.2^{j}	153.3±12.4^{l-n}	62.3±1.6^{l}
15.	*Desmodiummotorianum*(Houtt.) Merr.	62.6±6.5^{g-i}	253±6.2^{fg}	85.3±8.9^{i-k}	54±4.3^{g-i}	187±3.5^{hi}	75±5.09^{j-l}
16.	*Desmodiumtriflorum*(L.)DC.	62.3±7.1^{g-i}	245.3±4.1^{gh}	178.3±6.2^{b}	55.6±4.1^{g-i}	181±8.2^{ij}	129.3±7.3^{c}
17.	*Diclipterabupleuroides*Nees.	82.6±5.2^{d-f}	259.6±4.1^{ef}	146±2.9^{d}	74.6±5.2^{def}	202.6±5.2^{e-g}	110±8.2^{d-f}
18.	*Dioscorea bulbifera*L.	95±15.5^{cd}	PNV	PNV	78.6±3.3^{cde}	PNV	PNV
19.	*Dioscorea pentaphylla* L.	111.3±8.3^{b}	PNV	PNV	75.3±4.4^{def}	PNV	PNV
20.	*Elephantopusscaber*L.	144.6±8.05^{a}	271.3±6.5^{e}	PNV	92±6.5^{c}	211.6±8.4^{e}	PNV
21.	*Evolvulusnummularius*L.	82.6±10.6^{d-f}	229±4.08^{i}	128±6.2^{e}	74±4.3^{def}	169±8.2^{jk}	113±2.9^{de}
22.	*Flacourtia indica* (Burm.f.) Merr.	40±3.5^{l-m}	96±5.7^{n}	59±6.1^{m}	49.3±7.3^{g-j}	149±8.4^{m-o}	99.3±8.2^{e-h}
23.	*Flemingiachappar*Buch.-Ham. ex Benth.	61.6±3.6^{g-i}	192.3±2.8^{k}	PNV	48±5.6^{h-j}	159±8.2^{k-m}	PNV
24.	*Flemingiastrobilifera*R. Br.	88.3±4.6^{c-e}	214±5.2^{j}	PNV	75.3±4.1^{def}	156±9.9^{k-n}	PNV
25.	*Gardenia gummifera*L. f./	44.3±3.2^{j-m}	149.6±3.6^{l}	82±10.7^{jk}	41.3±0.9^{ij}	117.3±12.6^{q}	75.3±4.1^{j-l}
26.	*Hemidesmus indicus* (L.) R. Br.	50.6±8.9^{i-m}	114±4.3^{m}	82±10.7^{jk}	43.6±2.6^{ij}	82±5.8^{r}	72±8.6^{kl}
27.	*Holarrhena pubescens* Wall. ex G. Don.	58.3±6.2^{h-j}	148.3±6.2^{l}	101.3±6.5^{gh}	55±4.0^{g-i}	126±4.3^{pq}	89.3±7.3^{h-j}
28.	*Ichnocarpus frutescens* (L.) R. Br.	51±2.9^{i-m}	249.6±2.4^{fg}	145.6±4.1^{d}	54±4.3^{g-i}	184±4.3^{hi}	120±8.1^{cd}
29.	*Indigofera cassioides*Rott.*ex* DC.	52±3.2^{i-l}	255±8.5^{fg}	168.6±5.3^{bc}	51.6±1.6^{g-j}	210.6±8.2^{ef}	146±4.3^{b}
30.	*Meynaspinosa* Roxb.	59.6±7.4^{h-i}	300.3±9.3^{c}	161.3±6.5^{c}	54.6±4.1^{g-i}	255±4.0^{c}	150.6±9.9^{b}
31.	*Phaseolus adenanthus*G. Mey.	98±9.09^{c}	298±10.7^{cd}	PNV	86.6±8.0^{cd}	262±8.6^{bc}	PNV
32.	*Phyllanthus amarus*Schum & Thonn.	131.3±8.3^{a}	310±9.09^{bc}	PNV	122±17.3^{a}	274±4.3^{b}	PNV
33.	*Pueraria phaseoloides*(Roxb.) Bnth.	61.3±6.5^{g-i}	198.3±10.2^{k}	98.3±5.3^{hi}	61.6±2.3^{f-h}	166.6±12.4^{kl}	110±8.1^{d-f}
34.	*Scoparia dulcis* L.	42.6±5.7^{k-m}	192.3±5.5^{k}	112.3±7.5^{fg}	47±4.9^{h-j}	167.3±13.1^{kl}	96±4.3^{f-i}
35.	*Smilax ovalifolia*Roxb. ex D. Don.	83.6±8.1^{c-f}	233.3±6.7^{hi}	119.6±8.5^{ef}	84±4.3^{cd}	192.6±8.9^{g-i}	PNV
36.	*Vernonia cinerera*Less.	58.6±6.1^{h-j}	192.3±5.5^{k}	95.3±4.6^{h-j}	53.3±4.7^{g-i}	161.3±8.3^{k-m}	89±6.9^{h-j}

Note: PNV-Plant not visible, NA-Not Applicable, DP-Dead Plant, *Holarrhenaantidysenterica* (L.) Wall. *ex* Dc. = Syn. *H. pubescens* Wall. ex G. Don. , Each value represents mean of three soil samples. Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by Duncan's Multiple Range Test (DMRT), M-Monsoon, W-Winter, S-Summer. Data was the mean of 4 study sites.

Table 3: AM Fungal spore density at different study sites in Southwest Bengal

Sr. No	Site (Dist.)	Maximum Spore density/100g
1	Gopegarh Forest soil (Midnapore West)	415/100g
2	Termitarium soil (Bankura)	320/100g
3	Garden soil at Nepura (Midnapore West)	280/100g
4	Agricultural Soil at Lalgarh (Jhargram)	180/100g
5	Degraded Land (Purulia)	40/100g

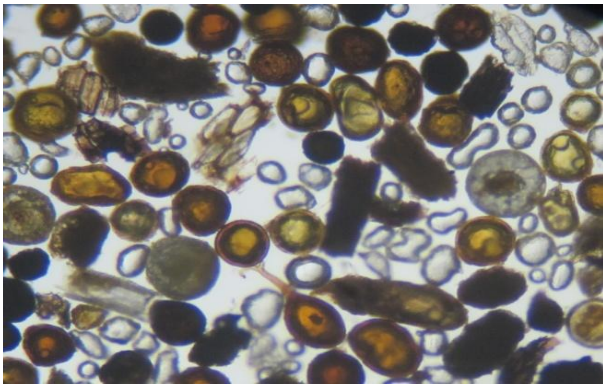

Fig. 1 IsolatedAMF spores from Rhizosphere soil

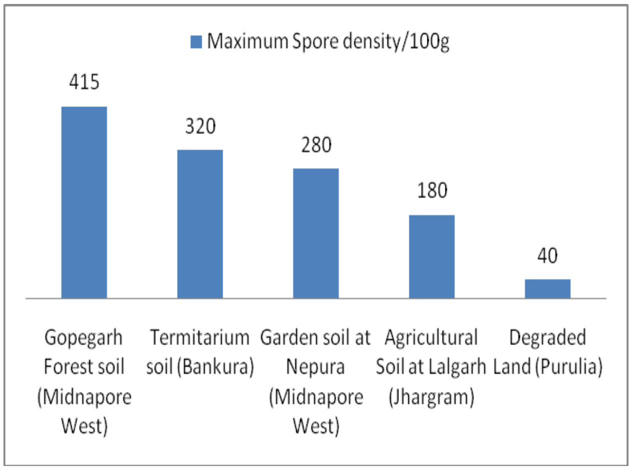

Fig. 2 AMF Spore density at different study sites under different management strategies

Fig. 3 ***Acaulospora laevis*** **(AMF spore), Photo credit- P. Ghosh**

Productivity and Yield of crop after inoculation with AMF spores:

After harvesting it was cleaned properly and accessed for biomass study. Result revealed that wet biomass of the mango ginger is increased with the increased spore density. No chemical fertilizers were used in all the cases. The weight of the biomass was more compared to control though in natural forest soil highest yield was recorded followed by termitarium soil, garden soil and agricultural soil. Degraded land soil showed minimum yield (Table 4, Fig. 4). Yield positively correlated with the number of AM spore density (Fig. 1) in each case.

Table 4: Productivity and yield of Mango ginger with AMF inoculum

Sr. No	Site (Dist.)	% of Yield	Spore density/2000g
1	Gopegarh Forest soil (Midnapore West)	180	8300±
2	Termitarium soil (Bankura)	176	6400±
3	Garden soil at Nepura (Midnapore West)	150	5600±
4	Agricultural Soil at Lalgarh (Jhargram)	100	3600±
5	Degraded Land (Purulia)	42	800±

Note: spore density not exact as per the increment of the soil amount taken in to study.

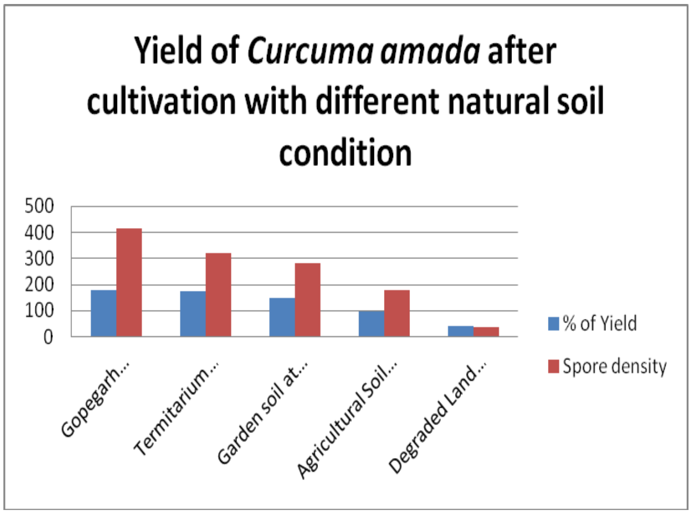

Fig. 4 Yield of Mango ginger with the activity of AMF spores under different soils

Challenges/Limitations of the Study:

The yield is not fixed for different places under different seasons. So, need broad experimental research and applications on varied crops. Soil substratum may be different if used along with organic manure then quantification is required before experiment.

Recommendations:

It is recommended that site specific AM fungal spore is more effective in case of inoculation, so large scale production of inoculum from AMF is encouraging to farmers for huge applications in various fields. In case of eco-restoration, earlier seed-based inoculation at experimental sites may be made after that degraded lands may be filled with crop plants or economic plants. It is also argued that before mass culture soil sterilization in a proper way must be made and after that careful way culture operations should be made to avoid the contamination. Before use of inoculum field trails may be made as per the statistical methods so replicas may be made to avoid the biasness during or after study.

VI. CONCLUSION

The study on AM biofertilizer and sustainable resource management for arid land cultivation practice has demonstrated the potential use of AM fungi to improve crop productivity, soil health, and water use efficiency in arid regions. The adoption of sustainable resource management practices, including the use of AM biofertilizer, can contribute to environmental conservation, climate change mitigation, and improved livelihoods for small-scale farmers. Result revealed that forest soil may be used as a potent source of AM inoculum production compared to degraded land and agricultural field in the regions where large-scale applications of chemical fertilizers take place. This means that undisturbed forest site is a reservoir of the economically important species of AM fungi that automatically conserved for future use. The novel species and its mixture may be used for better understanding compared to other species isolated from degraded land followed by agricultural fields. In near future people can use AM spores from forest soil to generate income through AM inoculum or fungal biofertilizer production. Here people are not aware to use AM biofertilizer for crop production yield but research result revealed that it enhances the productivity. So,Ggovt. Could motivate people to use AM biofertilizers for local use and crop production in future. It will help to maintain soil health for continuous crop cultivation.

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