Assessing comparative study on adaptive float farming against conventional farming system in inundated coastal plains of Sundarban

Submitted in partial fulfilment of the requirements for the award of degree of

M.Tech in Environmental Biotechnology

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by

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DECLARATION

I, Shreyasee Tudu, hereby declare that this thesis titled *"Assessing comparative study on adaptive float farming against conventional farming system in inundated coastal plains of Sundarban"* submitted to Jadavpur University in partial fulfilment of the requirements for the award of the degree of Master of Technology in Environmental Biotechnology is a bonafide record of the research work conducted under the guidance of my supervisor, Prof. Reshmi Das. This thesis represents my own original ideas and has not been submitted for any other degree or examination.

I further declare that all the sources of information and materials used in this thesis have been duly acknowledged and cited. Any assistance received from individuals, organizations, or other sources in the completion of this thesis has been properly acknowledged.

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CERTIFICATE

This is to certify that the Thesis Report titled "*Assessing comparative study on adaptive float farming against conventional farming system in inundated coastal plains of Sundarban*", submitted by Shreyasee Tudu (Roll no.: 002130904007) to Jadavpur University, Kolkata for the award of degree of Master of Technology in Environmental Biotechnology, is a bonafide record of the research work done by her under my supervision. To the best of my knowledge, the constituents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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It is hereby notified that this thesis titled "*Assessing comparative study on adaptive float farming against conventional farming system in inundated coastal plains of Sundarban*", is prepared and submitted for the partial fulfilment of the continuous assessment of Master of Technology in Environmental Biotechnology course of Jadavpur University by Shreyasee Tudu (Roll no.: 002130904007), a student of the said course for session 2021-2023. It is also declared that no part of this thesis has been presented or published elsewhere.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Final Examination for evaluation of Thesis

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ABSTRACT

As the global population grows, the imperative need of rising food demand places enormous strain on our limited resources mostly in coastal regions. Frequent changes in climatic catastrophes exacerbates this issue imposing constraints on conventional farming by destruction of crops and degrading soil quality. Consequently, we find need for an alternative farming approach that not only safeguard our environment but also supports our limited resources. Amidst the array of alternative practice, a long-forgotten method of floating farming resurfaced. We have revitalized this technique by designing a floating model that rests on water bodies, offering an extended agricultural land. This innovation was named as Floats for Integrated Agriculture Module (FIAM). The primary challenge faced by coastal areas is the soil salinity, which adversely affects crops. To cope up we have composed a mixture of cocopeat and vermicompost called FIAM growth media which facilitates good quality crops and also offers the added advantage of reduced weight maintaining the stability of floating surface. The aim of our thesis is to compare the long-forgotten conventional farming practice with float farming by developing an adaptive practice index using multiple-criteria decision analysis (MCDA) for agricultural sustainability on long term basis. This study of evaluating the use of growth medium was found to be superior in their physicochemical properties compared to the use of conventional soil. In addition, the study showed that the float farming system inclusive of using growth medium can be economically viable and environmentally sustainable. Therefore, it has the potential to be a probability unit for coastal population.

Keywords: climate change, Floats for Integrated Agriculture Module (FIAM), FIAM growth media, economical, sustainable

1. Introduction

Tropical Cyclones (TCs) are the deadliest natural catastrophes into existence causing major repercussions in many countries. Global climate change causes substantial increases in ocean temperatures, culminating to frequent and severe cyclones. The Bay of Bengal (BoB) region has seen a significant increase in hits. The graph depicts the data of cyclones that have formed in BoB over the last 20 years (data collected from IMD).

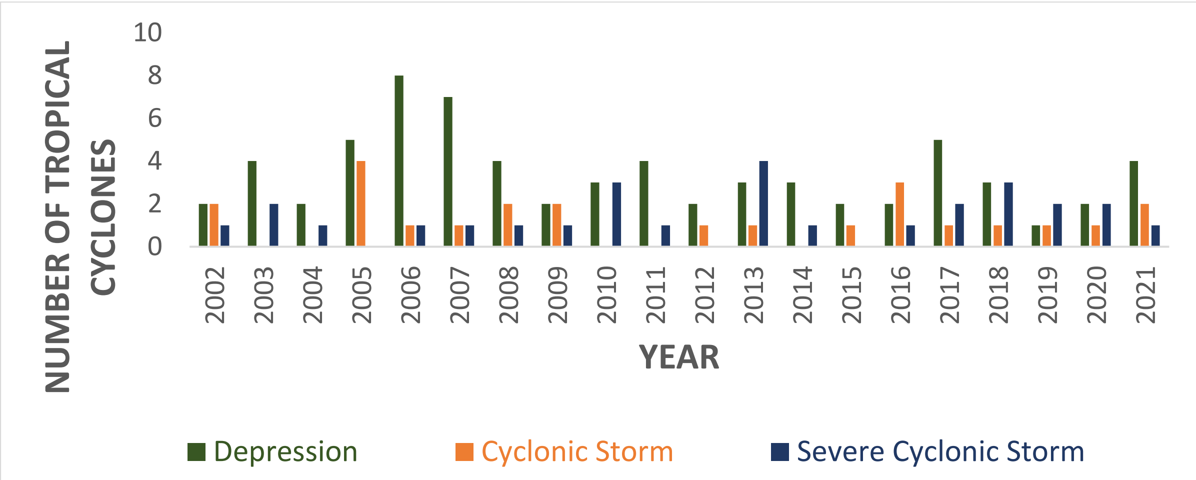

Fig 1: Graphical representation of cyclonic activity in BoB

Sundarbans, located in the vicinity of the BoB is a key transboundary and ecological hotspot for both India and Bangladesh. Sundarbans Reserve Forest is a Ramsar site in Bangladesh, established in 1992, and Sundarbans Wetland is a Ramsar site in India, designated in 2019 owing to its rich biodiversity. The Sundarbans coastline area has the world's highest population density, and the coastal population rely largely on the forest, estuary, and farmland for their livelihood. This site is well-known across the globe for possessing the world's largest delta and mangrove forest, which are surrounded by a diverse range of indigenous flora and fauna. The effects of tropical cyclones and their aftermath, such as embankment breaching, flood inundation, salt water intrusion, and waterlogging in agricultural land have a severe impact on coastal inhabitants in Sundarbans (Hoque et al., 2021). The diversified mangrove forest acts as a protection shield as it is resilient to the TCs. It also acts as a massive long-term carbon sink and retains terrestrial sediments (Ghosh et al., 2015). However, due to both anthropogenic and climatic factors, the Sundarban mangrove ecosystem is under severe threat from an increasing number of cyclones and higher storm surge levels. Cyclone Sidr made landfall in the Sundarbans in 2007, causing damage to roughly 40% of the area. Again, in May 2009, Cyclone Aila devastated Sundarban, killing thousands. At least 100,000 people were affected by this cyclone, and when cyclone Amphan struck in May 2020, this mangrove ecosystem became the worst victim of natural disasters (Mishra et al., 2021). Frequent cyclones and storm surges are the major challenges for us to protect this unique bioclimatic zone in a sustainable way. The intrusion of sea water into the cultivation field degrades soil health and thus crop production. Due to increased anaerobic conditions, inundation of low land areas with saline water also impedes biomineralization processes (Das et al., 2015). The cultivation fields in the flood-prone area of the Sundarban mangrove region have been harmed, and the economic loss should be compensated for using scientific methods. According to the West Bengal Government, agricultural land area decreased from 2,149.615 square kilometres in 2002 to 1,691.246 km^2 in 2009. The area suffers from low crop intensity since rice monoculture is practised seasonally, and horticulture crops are rarely cultivated. Most of the agricultural area is irrigated by rainfall from which only 12% is irrigated by rainfed ponds, tanks, and canals. Rainfall has grown more unpredictable, and its intensity has risen, inflicting more harm to agricultural productivity (Mahadevia and Vikas, n.d.). To protect the ecosystem from cyclones and storm surge is a major challenge and sea water intrusion negatively impact soil health. Therefore, to combat this situation a nature-based solution is required (NbS).

Global History of Float Farming

The potential of Floating Farming to save our future is not exaggerated. Since millennia various parts of world has been practising float farming including Southeast Asia such as Thailand, Cambodia, and Vietnam where it is locally known as 'floating garden' and in Amazon basin of South America locally known as 'floating fields.' Benefits such as increased land use efficiency, reduced water consumption and improved nutrients access for the crops were seen. There has been increasing interest in float farming as a sustainable and creative method to agriculture in recent years, particularly in locations where land is scarce or traditional farming practices are no longer practicable owing to climate change or other environmental problems. This has been a customary technique since antiquity. In Shan State of Myanmar, Inle Lake is one of the earliest recorded and most renowned sites for floating agriculture, where the Intha tribe has devised a distinctive technique for cultivating on the lake's water surface by creating floating islands out of natural and locally sourced materials. These floating islands were primarily used to grow crops like tomatoes, beans, etc., and they offer a paradigm of sustainable traditional agriculture in a biodiverse setting. Traditional agricultural systems, such as those found around Inle Lake, can serve as examples of resilient agricultural systems capable of dealing with global difficulties. Due to climate change and sea-level rise, particularly in coastal regions, these agricultural systems may offer food for local populations while also serving as appealing tourist sites, as in Inle Lake, therefore diversifying farmers' source of income (Oo et al., 2022). Floating rice farming is a technique for cultivating rice that uses rafts as a flood-response medium. This is feasible to extend on flooded fields in years because it can sustain rice output throughout the rainy season. However, because farmers are unaccustomed with farming in flooded regions, technical difficulties with rice growing must not be disregarded. Farmers require floating rice farming improvement and counselling as a result of the research findings in order to improve their abilities and produce ideal crops. The pioneering work of the

Faculty of Agriculture of UNS Surakarta in producing floating rice in Bojonegoro is expected to serve as a platform for farmers to accelerate the adoption of agricultural technological innovation (Irianto et al., 2019).

Excessive rainfall in both cross-border Indian catchments and sub-catchments inside Bangladesh resulted in massive surface runoff that eventually drained into rivers. This unexpected surge in flow surpassed the capacity of the rivers, flooding the surrounds and engulfing the primary production sector (e.g., agriculture), endangering the lives and livelihoods of the people living in the haor region (Dey et al., 2021). Floating farming, also known as "vasoman chas" in some rural regions of Bangladesh, is a long-forgotten traditional agricultural practice that is comparable to hydroponics, a scientific approach in which plants are cultivated in water and absorb nutrients from the water rather than soil. Water-hyacinth, aquatic algae, water-wart, and other water-borne creepers, straws, herbs, or plant leftovers are used to create floating agricultural platforms. Water-hyacinth (Eichhornia crassipes), aquatic algae, water-wart, and other water-borne creepers, straws, herbs, or plant leftovers are used to create locating platforms. Floating farming offers numerous advantages, including being environmentally benign since no additional fertilisers or manures are necessary, unlike standard agricultural system methods on plain lands; the area under the floating bed is more fertile than traditional land; and crops and fish may be produced together. As a traditional technique, floating farming is highly common in southern Bangladesh (Awal, 2014). In several southern areas of Bangladesh, such as Barishal, Gopalganj, and Pirojpur, where the cost-benefit ratio of vegetable growing varies from 1:1.6 to 1:2.6, it has become an alternative farming for vegetable production (Islam et al., 2015). The freshly prepared platforms had an average length of 4.6 m, a width of 1.4 m, and a height of 1.1 m. After 2-3 weeks, when the platform had decayed and was suitable to cultivate, the height dropped substantially to roughly 0.5 m. The platform sizes ranged from 3 to 33 m^2, with an average of 7 m^2. Water hyacinth harvesting typically began 4.5 weeks before platform construction. The time it took to build a platform ranged from 0.5 to 6 person days (1 person day = 8 h), with a mean of 2.5. Construction was nearly always sporadic, frequently occurring over a period of 7-10 days. The floating platforms were always placed in shallow water near the gardener's residence (maximum depth 2 m). During the monsoon, all sites were inundated, then dried out in the winter, when vegetables were grown in places potentially suitable for winter gardening (Irfanullah et al., 2008). When the water retreated, the farmers dismantled the semimoist floating platforms and incorporated the debris into the soil for winter food planting. Each allotment had an average area of 120 m^2. The floating beds continue for five to six months before being towed to shallow water by country boats using ropes and hooks to build ridge-type elongated platforms known as kandi. These are then employed in the wetlands as permanent crop beds (Islam and Atkins, 2007). The benefits of the floating garden vary depending on the size of the beds. Standard (15 × 4 × 3 ft) floating garden bed size areas provide greater benefit than small (12 × 4 × 3 ft) floating garden bed size areas since more may be cultivated, resulting in a higher yield for the cultivators. As mentioned by (Abdullah Al Pavel et al., 2014) the 0.26-year NPV obtained from each floating garden varies from US $73.92 to 1.53. Standard bed size regions (15 × 4 × 3 ft) obtained the highest NR of US$111.55, while tiny bed size areas received the lowest NR of US$12.63. As a result, the net benefit of a floating garden increases with bed size. Additionally, CBA (US $3.67) is more advantageous for the usual bed size (15 × 4 × 3 ft) of a floating garden. A project is impossible if the CBA value is less than one. The Haor region is situated below the hilly areas of India's states of Assam, Meghalaya, and Tripura. Due to its geographical location, the region experiences heavy rainfall and flooding (Kartiki, 2011; Quddus et al., 2014). Also, the state of Kerala has initiated a program of ‘Floating Agriculture’ to encourage farmers to grow crops in floating platforms in water bodies such as rivers, lakes, ponds, etc., This initiative seeks to boost agricultural output, create jobs, and encourage the sustainable use of natural resources. Similarly, in the north-eastern Indian state of Manipur, farmers are employing floating gardens to cultivate commodities such as water spinach, tomatoes, and cucumbers in Loktak Lake, the biggest freshwater lake in the region. The floating gardens were composed of soil and organic materials which were secured to the lakebed using bamboo poles. The floating gardens have helped farmers increase agricultural production and enhance their livelihoods. Furthermore, this study aims to introduce an innovation for floating farms which can be utilized as a nature-based solution (NbS) for resilience towards climatic change. Also, to compare the production potential of the innovation and traditional farming methods along with the benefit cost and to develop an adaptive practices index using Multiple-criteria decision analysis (MCDA) which can be used as a probability unit for flood-affected individuals. The present study can be used to plan disaster mitigation to reduce the risk of food scarcity in anticipation of cyclones.

2. Materials and methods

2.1 Study area

The focus of this study is the Sundarban region located in the South 24 Parganas district of West Bengal, India. This area is susceptible to natural calamities such as salt-water incursion, waterlogging, and prolonged inundation. The Sundarban region is home to the Royal Bengal Tigers and various species of flora and fauna. In 1987 it was designated as UNESCO World Heritage Site. The region is a low-lying delta that has earthen embankments. The study area has a total population of 475,651 (Census of India 2011) of which 64% are literate. The area has a total of 306,882 households (Census of India 2011). More than 70% of the population still depends on agriculture, forestry, and pisciculture for their livelihoods (Ghosh and Mistri, 2020). Since the region experiences a tropical monsoon climate, farming operations are heavily reliant on rainfall.

2.2 Design and description of innovation

2.2.1 Floats for Integrated Agriculture Module (FIAM)

The fabrication of Floats for Integrated Agriculture Module (FIAM) comprised of a floating bed made up of bamboos (8 x 12 ft) were constructed and floated on the water surface using 6pcs of 200L High Density Polyethylene Drums (HDPE). Total 30 no. of growbags were placed on the shaft which contains the soil used for growing of plants. A detachable screen (climber net) intended to prevent direct rainwater from falling on plants was used to cover the FIAM.

2.2.2 Preparation of growth medium

For the experimentation growbags of 40 x 24 x 24 cm were used. These grow bags were punched with two holes underneath to facilitate drainage, maintain proper aeration, and prevent compaction. The experimental growth media used in the study was a soil-less mixture fabricated primarily using vermicompost and cocopeat. To make about 10-12 kg of growth medium, 6kg vermicompost was mixed with 4kg cocopeat, 1 kg soil, 50g TDV, 50g mustard cake, 50g bone dust and 50g NPK. The combination of all these elements ensures optimal growth and survival rate of plants.

Fig 2: Preparation of FIAM growth media

2.2.3 Cost of construction of FIAM

Table 1: Detailed cost breakdown of a single Shaft

Items	Quantity	Unit	Rate (Rs)	Total Amount (Rs)	Total Amount ($)
Bamboo	30	Pieces	250	7500	91
Plastic shade	2	Kg	160	320	4
Shade Net (14'/10')	1	Piece	450	450	5
Drums	6	Pieces	1150	6900	84
Climber Net	1	Kg	450	450	5
Tyre rope	3	Kg	280	840	10
Miscellaneous			1500	1500	18
Total				Rs 17960	$217

The Shaft has a shelf-life of 3 years. After that the bamboo should be changed while the other materials can be reused. This makes it cost-efficient. Therefore, circularity in climatic resilient agriculture can be observed.

Fig 3: Floats for Integrated Agriculture Module (FIAM)

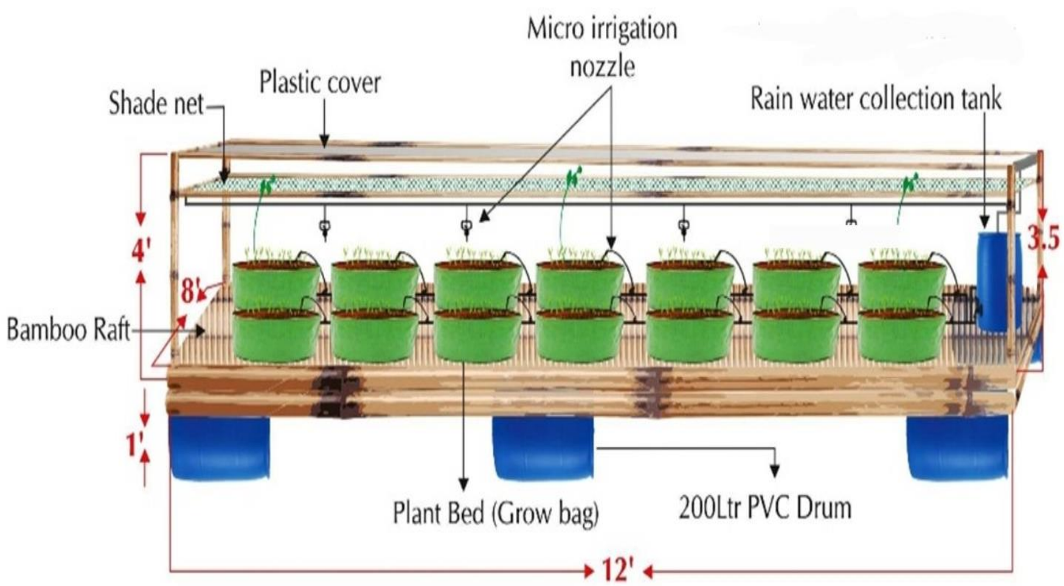

Fig 4: Schematic diagram of FIAM

2.3 Cultivar selection and agronomic efficacy assessment

The influence of growth media on yield and quality of tomato (Solanum lycopersicum var. Patharkuchi), chilli (Capsicum annuum var. Sonamukhi), and brinjal (Solanum melongena var Jhuribegun) belonging to the family Solanaceae was studied using growth media as well as conventional studies on FIAM for the winter season. The type of variations and application doses were considered as main experimental factors during the studies. Grow bags were used to hold growth media and conventional soil in each FIAM at Sundarban, India (22.091982 ° N, 88.892982 ° E) during December, 2022 to February, 2023. Total 15 number of bags each for growth media and conventional soil were set up on each FIAM. Seedlings of nearly the same height were purchased from a local nursery and planted, two in each growbag. Conventional Soil was collected from Tipligheri village of Sundarban, West Bengal, India. Conventional Soil colour was dark grey (10YR 4/1) while the colour of growth media was black (2.5Y 2.5/1) according to standard Munsell Soil Color Charts having pH between 6.0 to 7.0. Common disease infestations such as leaf curls and black spots were found during cultivation so pesticides such as Urea, Potash and Phosphate were applied. To determine physiognomic changes, plant growth was assessed at the conclusion of the season, right before harvesting. Over the course of cultivation period, the temperature ranged from 35°C to 14°C.

2.4 Growth media analysis before and after cultivation

Seasonal monitoring of physicochemical parameters and main nutrients for cultivar growth medium was carried out. Growth media samples were collected from selected measuring stations during the winter season for in-situ measurement and laboratory analysis and stored at 4°C for the evaluation of biological properties at two-time frames i.e, on zero day and post-harvest. Nutrient parameters were examined in the chemical laboratory of the School of Environmental Studies (SOES) at Jadavpur University. Soil pH measured using a digital pH meter (LMPH-10, Labman Scientific Intruments Ltd. Chennai, India). Soil Organic Carbon (SOC) was estimated following the methodology of Walkeley and Black (1934). Available Nitrogen was determined by Kjeldahl method of Subbiah and Asija (1956), Total Phosphorus and Available Potassium contents were measured by vanadomolybdophosphoric acid colorimetric and flame photometric meythods (Radojevic and Bashkin 1999). Micronutrients such as Zinc, Boron, Copper, Manganese, and Iron was estimated using atomic absorption spectroscopy (Scientific Research Laboratory, Kolkata, India). Soil was collected from Sundarban, India. Parameters analyzed included soil colour identification with standard Munsell Soil Color Charts (Torrent and Barron 1993), soil pH was measured potentiometrically, water holding capacity was determined using gravimetric method (Radojevic and Bashkin 1999). Salinity was measured using refractometer (Erma Inc., Tokyo, Japan). For comparing the soil applications Student's *t*-test was conducted.

2.5 Benefit-cost ratio analysis of the cultivation system

The economic feasibility of deploying growth medium in commercial agriculture was examined. The seasonal expenses covered growbags preparation, seedling procurement and transplantation, fertilization, pest and weed management, irrigation, and harvesting. The prices of key inputs and labour costs are summarized in table. During field cultivation, a wage rate of INR 250 per head was considered as labour cost. The yield per FIAM income was calculated using the average market price of INR 30 kg^{-1} for tomato, INR 80 kg^{-1} for chilli and INR 50 kg^{-1} for brinjal. The benefit-cost ratio in terms of net return from tomato, chilli and brinjal for winter seasons over 10 number of FIAMs was then calculated.

Fig 5: Experimental setup of 10 number of FIAMs

3. Result

3.1 Characteristics of FIAM growth media and conventional soil

The average pH of FIAM growth media was 7.31±0.10 and conventional soil was 6.24±0.22. Average organic carbon was estimated to be 195.97±9.71g kg^{-1} and 65.78±5.44g kg^{-1} for FIAM growth media and conventional soil respectively. N, P and K was determined to be 1849.33±159.21mg kg^{-1}, 1026.67±161.65mg kg^{-1}; 3.48±0.96mg kg^{-1}, 1.95±0.97mg kg^{-1};

4001.16±164.96mg kg^{-1}, 308.50±35.33mg kg^{-1} for FIAM growth media and conventional soil respectively. Estimated Copper (Cu) was 176.40±1.22mg kg^{-1}, 35.93±0.72mg kg^{-1}; Manganese (Mn) 509.36±12.54mg kg^{-1}, 425.00±25.83mg kg^{-1}; Boron (B) 1.43±0.10mg kg^{-1}, 1.05±0.02mg kg^{-1}; Zinc (Zn) 260.80±3.63mg kg^{-1}, 79.36±2.50mg kg^{-1}; Iron (Fe) 20548.93±790.55mg kg^{-1}, 31246.10±565.72mg kg^{-1} for FIAM growth media and conventional soil respectively. Water holding capacity was observed to be 10.50±0.88 ml for FIAM growth media and 6.20±0.20 ml for conventional soil. Salinity of FIAM growth media and conventional soil was estimated to be 2.5±0.8‰ and 10 ±3.5‰ respectively.

3.2 Effects on plants growth

Using FIAM growth media during cultivation of tomato, chilli and brinjal demonstrated higher crop yield than conventional soil system. In contrast, plant growth was somewhat similar in both cases. Yield for FIAM growth media was more due to the greater presence of NPK than in conventional soil which results in better productivity. *Table 3* revealed significant difference($p<0.01$) in the yield between different cultivation system. Our investigation also evidenced higher concentrations of NPK and OC resulting in better C:N ratio and greater microbial growth. FIAM growth media had relatively higher micronutrients level than that of conventional soil. Increased production of leaves helped to elaborate more photosynthates and induce flowering, thus effecting early initiation of flower bud on FIAM growth media. Here, yield is the representation of physiological and morphological factors of the outcome of solar energy trapping and conversion. This may aid in production of additional carbohydrates, which may be the reason for greater quantity of fruits and fruit weight. The higher components of the three crops may be account for the increased number of fruits and fruit weight obtained in plants cultivated in FIAM growth media system.

Table 2: Comparative analysis of the growth parameters of tomato, chilli and brinjal plants

Parameters	Tomato		Chilli		Brinjal	
	Conventional Soil	**FIAM Growth media**	**Conventional Soil**	**FIAM Growth media**	**Conventional Soil**	**FIAM Growth media**
Plant height(cm)	120.67±9.02	$121.67±1.15^{ns}$	110.00±10.00	$100.00±36.06^{ns}$	98.33±7.64	$100.67±11.02^{ns}$
Number of leaves	151.67±7.64	$152.00±2.65^{ns}$	86.67±7.64	$108.33±20.55^{ns}$	23.67±2.52	$23.33±5.77^{ns}$
Leaf surface area (cm^2)	12.67±2.08	$14.67±0.58^{ns}$	14.67±2.52	$12.33±2.52^{ns}$	13.67±1.53	22.33±1.15**
Stem diameter (mm)	13.6667±0.4933	$13.5967±0.5254^{ns}$	12.4667±0.5033	17.8033±0.5764*	6.533±0.702	17.333±2.517**
Number of buds	11.33±6.43	140.0±10.00**	193.33±11.55	$167.33±56.23^{ns}$	24.00±2.00	18.00±3.46*
Number of fruits	13.67±4.73	$9.67±0.58^{ns}$	108.33±18.93	$127.67±65.91^{ns}$	7.00±2.65	$5.67±2.08^{ns}$
Average fruit weight (g)	395.33±54.64	591.67±166.46*	325.00±56.79	487.00±295.44ns	254.67±92.98	346.67±117.19*

Differences estimated with Student's *t*-test. Values represented as mean of replicates per parameters (n=3) with standard deviations. **ns:** not significant, ***** $p < 0.05$ and ****** $p < 0.01$

3.3 Effects on soil parameters

Proper supply of N improved structural, physico-chemical and biological properties of the soil as evident from (Table 3) FIAM growth media attained higher oxidizable OC and available NPK concentrations. Micronutrients were relatively higher in FIAM growth media. Over all OC had a strong positive correlation with proportion of macronutrients (PCA= 0.77). In contrast, the use of N was moderately correlated (PCA=0.75), P and K was strongly correlated (PCA=0.79, PCA=0.73 respectively). Other micronutrients such as Cu, B and Zn was positive but moderately correlated (PCA=0.47, PCA=0.28 and PCA=0.38 respectively). According to PCA analysis, the Fe, Mn and Salinity were negatively correlated (PCA=-0.71, PCA=-0.07 and PCA=-0.76 respectively).

Table 3: Characterization for FIAM growth media and conventional soil

	A	B	C	D	E	F
1	Soil Parameters					
2		Growth Media	Before Cultivation		After Cultivation	
3				Tomato	Chilli	Brinjal
4	pH	Conventional Soil	6.2400±0.2254	6.2433±0.0850ns	6.0600±0.0693ns	6.2733±0.0493ns
5		FIAM Media	7.3133±0.1026	7.3000±0.2606ns	7.0867±0.1079*	7.3900±0.2623ns
6	Organic Carbon (g/kg)	Conventional Soil	65.78±5.4408	60.9800±13.6874ns	62.39±12.6623ns	58.03±4.4036ns
7		FIAM Media	195.9733±9.7144	396.0633±6.2803**	450.2000±14.3936**	299.4467±37.9268*
8	Available Nitrogen(mg/kg)	Conventional Soil	1026.67±161.6581	466.67±161.66ns	742.00±275.63ns	467.5300±185.6404ns
9		FIAM Media	1849.33±159.21	746.67±161.66*	1.26.67±161.66*	1120.00±280.00ns
10	Available Phosphorus(mg/kg)	Conventional Soil	1.958008±0.97671138	0.24353333±0.19014324ns	0.13000000±0.03473579ns	0.64000000±0.35898284ns
11		FIAM Media	3.48739733±0.96675065	10.83236267±1.98988045*	9.03021600±2.79513467ns	7.12091467±0.79354506ns
12	Available Potassium(mg/kg)	Conventional Soil	308.500±35.334	468.067±47.947*	289.6200±34.7640ns	334.1500±63.3044ns
13		FIAM Media	4001.167±164.968	4346.333±76.602*	3771.367±118.501ns	3770.400±62.764ns
14	Copper(mg/kg)	Conventional Soil	35.933±0.723	34.000±0.529**	33.600±3.100ns	33.8600±1.3634ns
15		FIAM Media	176.400±1.229	112.700±5.543**	155.533±22.617ns	169.267±8.515ns
16	Manganese(mg/kg)	Conventional Soil	425.000±25.833	402.667±8.133ns	412.6400±56.1746ns	417.0200±41.9783ns
17		FIAM Media	509.367±12.543	383.233±28.688*	509.367±12.543ns	499.600±33.641ns
18	Boron(mg/kg)	Conventional Soil	1.0533±0.0252	0.8433±0.0503*	0.6500±0.2152ns	0.8600±0.0529*
19		FIAM Media	1.4333±0.1007	1.2167±0.0737ns	5.0367±0.1419**	3.3167±0.1710**
20	Zinc(mg/kg)	Conventional Soil	79.367±2.5007	77.133±0.833ns	76.2300±6.5480ns	74.8900±6.3871ns
21		FIAM Media	260.800±3.635	163.200±14.233**	238.200±17.840ns	271.067±27.248ns
22	Iron(mg/kg)	Conventional Soil	31246.100±565.723	31880.233±472.048ns	31189.000±357.278ns	31302.133±1377.994ns
23		FIAM Media	20548.933±790.551	13363.000±1237.530*	13295.733±801.365**	15787.633±2340.436ns
24	Water Holding Capacity(ml)	Conventional Soil	6.200±0.200	6.500±0.529ns	6.600±0.600ns	6.300±0.200ns
25		FIAM Media	10.500±0.889	18.500±2.524*	14.800±2.443ns	12.800±2.227ns
26	Salinity(ppm)	Conventional Soil	10000.00±3500.00	5000.00±2179.45ns	6000.00±1928.73*	6000.00±1900.00ns
27		FIAM Media	2500.00±888.82	0.00*	0.00*	0.00*

Differences estimated with Student's *t*-test. Values represented as mean of replicates per parameters (n=3) with standard deviations. **ns:** not significant, ***** $p < 0.05$ and ****** $p < 0.01$

3.4 Economics of Conventional systems vs FIAM

Benefit-cost outcome of tomato, chilli and brinjal was calculated from a single FIAM having total 30 number of growbags, 15 each containing conventional soil and growth media. We obtained highest net return from conventional system followed by growth media during FIAM experimentation. However, the cultivation cost was higher for conventional system due to greater input of fertilizers, labor charges and irrigational purposes. In case of climate crisis, we found profitability from the FIAM being used as floating shaft. Table summarizes prices of various inputs, labor cost and net return as mentioned earlier in section 2.5. For tomato, chilli and brinjal, we obtained on average 0.09,1.4 and 0.07 for conventional soil and 1.64, 4.28 and 1.76 for growth media respectively. Conventional soil when used was advantageous over the use of growth media in business acumen.

Table 4: Production Cost for 10 number of FIAMs (INR)

Parameters	Tomato		Chilli		Brinjal	
	Conventional Soil	FIAM Soil	Conventional Soil	FIAM Soil	Conventional Soil	FIAM Soil
Seedling Purchase	120	120	160	160	60	60
Price of chemical fertilizer	350	0	200	0	500	0
Labor charge for transplantation, fertilizer application and harvesting	1000	750	1000	750	1000	750
Irrigational purpose	300	150	300	150	300	150
Economic return	1800	2700	4000	5600	2000	2650
Benefit Cost ratio	0.09	1.64	1.4	4.28	0.07	1.76

4. Discussion

People are frequently affected by food insecurity and employment loss as a result of changing environmental circumstances. A nature-based approach was required to address this dilemma. As a result, a practice known as floating farming was identified, which inspired our concept of FIAM. The trial phase commenced in the year 2017 at Majuli, Assam which is known as the world's largest river island, encompassing an expansive area of 352 km^2 and accommodates an approximate population of 167,304 Approx (Census of India 2011). This pioneering initiative of South Asian Forum for Environment focused on cultivating vegetables using floating rafts and received sponsorship from NABARD with administration of Majuli actively supporting. The design of FIAM was developed by preparing a bamboo frame of (4 x 6 ft) in rectangular shape. A hydrofoam base was laid over the frame and covered with a layer of plastic wire mesh and a last layer of thermocol sheet to make it float over water surface. The floor of each float is constructed from 8ft split sections of basal bamboo. On the surface of the floats, 10-15 grow bags were placed in distinct rows. These rows would be filled with FIAM growth medium (an organic potting mix composed of 20% soil, 40% vermicompost, 20% saw dust and 20% sand) and used as vegetable beds. But various disadvantages were observed with this model such as the thermocol sheet which is considered harmful for the environment. Therefore, in its second experimental phase the thermocol sheet was excluded, a shed net was used to cover the FIAM from heavy showers and the size of bamboo frame was increased to (4.5 x 8 ft), also the project expanded to Saatkhira, Bangladesh after receiving funds from GDN during 2018-2019. After so many changes, in the year 2020, a new model was established which is being used in our experiments currently. This model received great appreciation and popularity amongst people residing in coastal areas of Majuli, Saharsa, Kumirmari, Amtali and Saatkhira of India and Bangladesh. Following the satisfactory results GDN, GIZ and PWC (IRFAAN

Project) extended their support and Japan Social Development Fund scaled up the project by including pisciculture, crop calendar, solar micro-irrigation, crab fattening and IPM technique which embraces the concept of multi-farming. Finally, in 2021-2022 a removable climber net was added to the general framework and bottle drip micro-irrigation was introduced. This project is now scaled up by the introduction of apiculture, livestock, and mangrove restoration by United Nations Development Programme (UNDP). This module follows zero-tillage method so no additional GHG inclusion is taking place, moreover facilitating the blue carbon sequestration in mangrove ecoregion. Augmentation of aquafarming with the practice of float farming helps supplement the income of local communities and contributes to alleviation of poverty. It requires about one-tenth of water used in contrast to the optimal water demand in the field hence, saving the water resource due to the water retention capability of the FIAM growth medium. Women have been at the forefront of implementing these practices. It provides greater food security by increasing land output and supporting capacity for poor and landless people. This climate strategy is an amalgamation of scientifically supported best practice method and indigenous traditional knowledge emerged from NbS. Thus, it plays huge role in achieving Sustainable Development Goals (SDGs) especially ‘Zero Hunger’ (SDG 2), ‘Gender Equality’ (SDG 5) and ‘Climate Action’ (SDG 13).

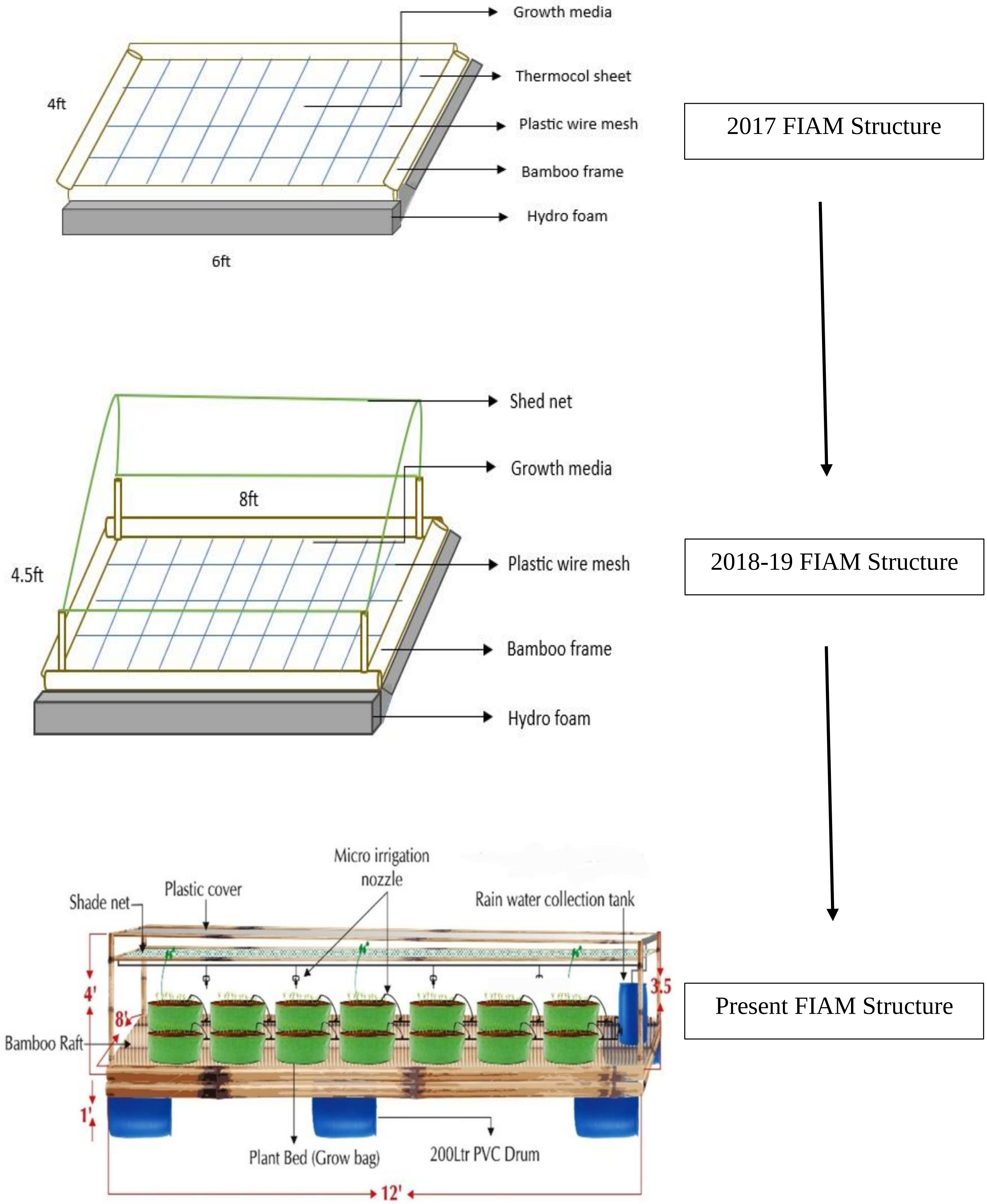

Fig 6: Evolution of FIAM

Our research was carried out initially for two seasons i.e., monsoon and winter. In our first trial during monsoon, cultivar selected were lady's finger *(Abelmoschus esculentus),* chilli *(Capsicum frutescens L.)* and bitter gourd *(Momordica charantia L.)*. The plants grew for around 2 months but failed to yield due to continuous rainfall. Heavy rainfall clogged the FIAM growth media due to its high-water retention capacity. Excessive soil moisture caused rotting of roots which developed wilting disease and necrosis. Consequently, this resulted in failure of our monsoon season crops. Whilst amid winter season no climatic disturbance was observed. As a result, the winter season was a success.

Soil organic carbon is reduced in arable soil due to intensive agricultural practices. FIAM growth media can be an appropriate approach to increase soil organic carbon due to its no-tillage practice. Furthermore, this growth media supplied boron (B), zinc (Zn), copper (Cu) and iron (Fe) thus enhancing crop quality and productivity. N is essential for chloroplast progression in higher plants, it promotes cell elongation and encourages plant growth. P helps in energy transfer, photosynthesis and translocation. K acts as an antibody for resisting plant disease (Roy et al., 2013). Zn and Fe deficiencies have a substantial impact on protein and chlorophyll synthesis in higher plants, whereas B improves sugar transport and causes early blooming (Bhunia et al., 2021). Therefore, FIAM growth media was discovered to be more beneficial for plant growth and in conventional soil.

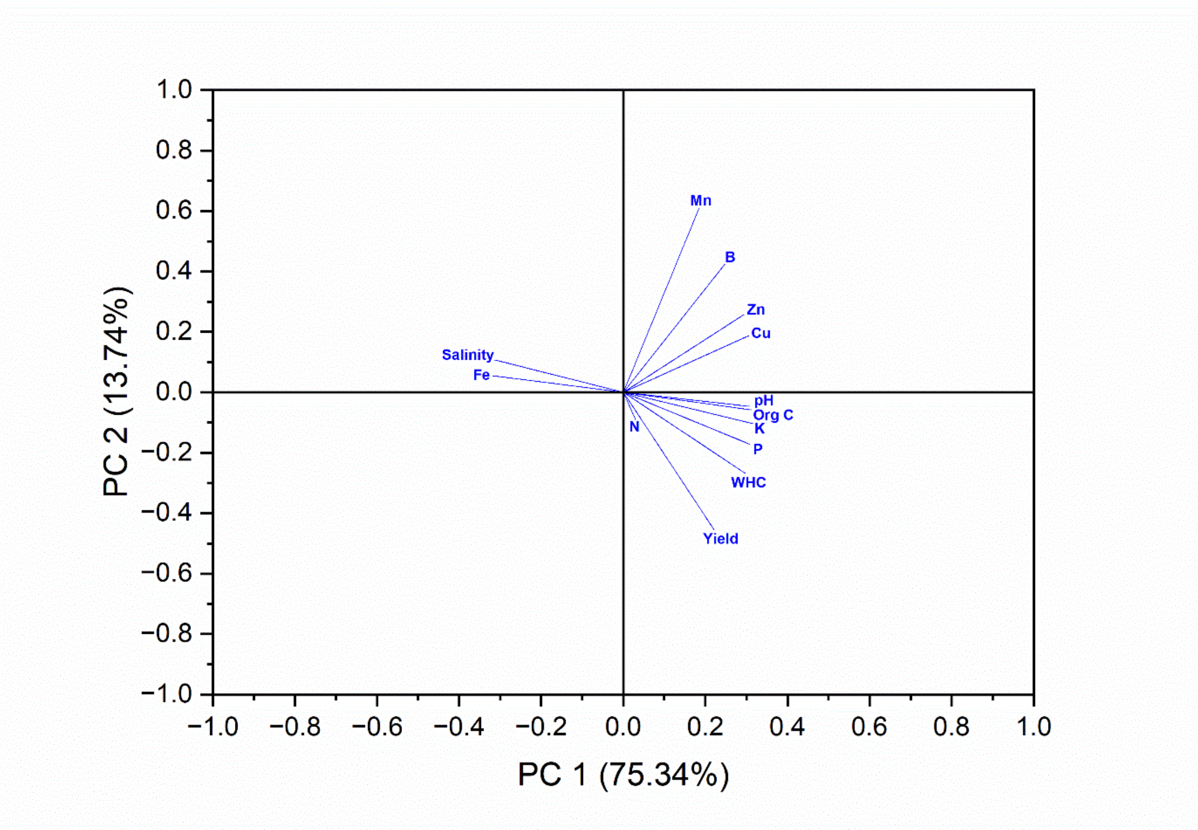

Fig 7: Biplot of the multivariate principal component analysis (PCA) performed on soil physico-chemical characteristics and their possible correlations with FIAM growth media

When compared to conventional soil, the FIAM growth media exhibited superior plant growth with notable variations in the amounts of growth achieved. Extensive research implementing Principal Component Analysis (PCA) showed NPK, OC and WHC as the key parameters impacting plants growth in both systems. This component played a pivotal role in determining the overall productivity and development of the said systems. A significant disparity in plant growth levels was evident between FIAM growth media and conventional soil. The concentration of essential micronutrients as mentioned in soil parameters *(Table 3)* was found to be comparatively higher in FIAM growth media. Among those Cu, B and Zn positively involved in plant development while Mn and Fe represented negative correlation in FIAM growth media due to higher availability of essential macronutrients in comparison to conventional soil having a considerable impact on their growth trajectory. The WHC is another important factor that influences the composition of soil and media followed by plant growth. During monsoon season, the FIAM growth media revealed a greater proclivity for rainwater absorption, resulting in negative correlation such as wilting disease and necrosis, eventually leading to plant mortality. The PCA also showed a strong negatively correlation with the plant yield implying that this component could be the reason of delayed plant growth and mortality in the conventional system.

Floating agriculture is an environmentally beneficial method of expanding agricultural land availability. This approach is sustainable and profitable in developing countries, improving economy and food security. Conventional land-based agriculture requires it to be protected behind embankments leading to have calamitous effects on environment. In contrast, floating agriculture uses water body subsequently decreasing land use. This procedure contributes toward maintaining healthy ecosystem. The structure of floating shaft is made up of environmentally available materials. The FIAM growth medium in use promotes no-tillage method leading to store more organic carbon in the soil. Due to its ease of availability of raw materials for the construction of FIAM, it is suitable for poverty driven people as well. At present acceptance of this practice is currently relatively low due to minimal awareness. This model has the potential to become a saviour amidst severe climatic events. Our research was conducted solely for experimental purpose; therefore, the expense of construction of FIAM was not included in benefit-cost ratio. However, beneficiaries can draw inspiration from our module and prepare it in more economically efficient manner.

Fig 8: Empowering farmers towards the use of FIAM for sustainable food production systems for better future.

The study conclusively proves that using FIAM growth media produces various benefits, including increased crop yield, improved soil fertility and increased farmer profitability. This stratergy provides a feasible alternative to traditional agriculture systems and aids in mitigating agricultural land loss, which has become an urgent concern in South Asian countries due to frequent climatic changes. Implementing FIAM growth media allows framers to attain dual benefits by positively impacting crop yield. This approach also contributes to a large reduction in organic carbon levels. Adopting this technique not only makes sustainable agricultural production possible but also benefits a variety of stakeholders while developing local employment possibilities, especially for women and preserving a clean and healthy environment.

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