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Indigenous wisdom for sustainable mountain agriculture in the eastern Himalayas (Meghalaya)

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ABSTRACT

Sustainable hill farming necessitates a balance between economic growth and environmental protection. Due to unsustainable hill farming, the mountain ecosystem in north-east India (NEI) is now at greater risk of soil erosion and degradation. The adoption rate for advanced watershed engineering and mechanical measures (WEMM) among resource-poor hill farmers is extremely low. WEMM's high initial investment, extremely skilled approach, and the challenge of maintaining it post-project period are the reasons for this. Despite low productivity, tribal hill farmers in some parts of the region have been able to maintain natural resource conservation and livelihood security by using generations of old indigenous traditional knowledge (ITK) and wisdom. Without proper documentation, the eco-friendly ITK-based indigenous hill farming and soil water conservation wisdom in the region will disappear with time. Documenting these ITKs and age-old practices can help us refine present-day agricultural practices for better location-specific field-scale adaptability and land productivity while conserving and sustaining natural resources in mountain ecosystems. This study documented some of the most commonly used ITKs for hill farming, including rain water harvesting and soil and water conservation (SWC) practices from one of the most prominent crop-growing hill districts (>1800 m mean sea level) in Meghalaya, *i.e.* east Khasi hills. Through surveys, field visits, personal interviews, semi-structured interview schedules, focus group discussions, and observation methods, information was gathered. Scientifically validating and refining these documented ITKs and farming wisdom can enhance the adaptability of mechanized yet sustainable farming practices on a large-scale basis. This could help develop sustainable technologies to enhance low productivity and conserve natural resources in the hilly ecosystems of the Northeast and other Himalayan ecosystems.

1. INTRODUCTION

In north-east India (NEI), tribal resource-poor farmers have used ITK and wisdom passed down through generations to maintain their primary hill agriculture-based livelihood security. ITK's current form is environmentally friendly and sustainable in terms of soil health and water conservation, especially in hilly terrains, but it is low yielding and mostly subsistence-oriented. This risk-prone hilly region is experiencing a transition in traditional agricultural practices due to the growing population and demand for more food. Farm mechanization, input intensive cultivation (*e.g.* high-yielding varieties, water, nutrients, herbicides, pesticides, etc.), and reshaping land configuration along steep slopes are some of them. Modernization efforts are improving agricultural productivity, but they are causing new challenges to maintain soil health, reduce soil acidification and erosion, address abiotic stresses, and conserve water. The gradual disappearance of age-old, eco-friendly, and inherited ITK-based traditional hill farming wisdom in the region is happening due to this. Documenting ITKs and practices that are captivated by the local farming communities is of great significance, especially in the refinement and greater adaptability of recently introduced modernized agricultural practices. The current low land-productivity could be improved while enhancing the sustainability of soil and water resources in the fragile hill ecosystem.

The north-eastern Himalayan region of India is distinguished with a mix of mountain ranges, plateaus, low hills, and intermontane valleys that are complex, diverse, and equally vulnerable to eco-fragility, marginality, and inaccessibility, resulting in a future with highly uncertain and risk-prone agriculture. Only 16.2% of the total geographical area is used in agricultural practices (Choudhury *et al.*, 2021). The undulating topography (>77% of the area), sloping uplands, and orography led to wide spatial and temporal variability with high-intensity rainfall (annually 1200-11500 mm). Intermittent to terminal water stresses during critical crop growth periods, and soil acidity-induced fertility, are among the major constraints in achieving optimum crop and water productivity (Choudhury, 2023). Agriculture's ability to achieve optimal food production in the region is hindered by a lack of receptivity towards modern agricultural technologies, steep slope cultivation and severe (Ramachandran *et al.,* 2023) water erosion, local low-yielding crops and varieties, poor transportation and marketing networks, as well as socio-economic conditions. The state of Meghalaya, which consists of the Khasi hills, Jaintia hills, and Garo hills, with a total area of 2.24 M ha, is largely agrarian. It is home to 200 of the 635 tribal groups in the country and has a lower level of industrial and economic development (NCERT, 2017). The primary farming systems in the state are shifting cultivation and terrace (*bun*) agriculture. In valley lands, foothills, and forest plantations, terrace cultivation is the primary practice, while shifting cultivation is used in forested hills. To maintain ecological balance, ITK and locally available resources are used in these farming systems (Jeeva *et al*., 2006). These ITKs are a collection of knowledge, wisdom, and practices that were developed and maintained by the local people with a long history of relations with the natural environment. Documenting these ITKs on various aspects of farming before the old generation passes away is crucial as they have significant practical utility for the sustainability of the mountain ecosystem. Future planning for the conservation of natural resources, biodiversity, and soil health care may also benefit from this. Using this background information, we aimed to gather and document the ITKs followed by farmers in Meghalaya. Farmers in these regions have a belief that some of the indigenous agricultural production systems/activities and their ancestors' management practices would assist in conserving natural resources while sustaining their livelihood. In addition, the documented ITKs should be enhanced with adequate interchange among various stakeholders, such as researchers, extension workers, and policymakers, through journals, newspapers, and other media devices (Pandey *et al*., 2017).

2. MATERIALS AND METHODS

Study Area

The east Khasi hills district is one of the 11 districts in the State of Meghalaya, occupying an area of 2,748 km^2, lies between 25°07” and 25°41”N latitudes and 91°21” and 92°09”E longitudes. This district is located at an elevation of 1220 to 1830 m above the mean sea level (MSL), making it the highest altitude district in the state. The district is part of the warm, humid agro-eco sub region (ASER 17.1) (NBSS&LUP). The climate of the district is influenced by its elevation. The higher elevations experience a temperate climate, while the lower elevations experience a relatively warm and humid climate (Goswami, 2008). The district is home to the world's highest rainfall receiving Cherrapunji plateau (annually exceeding 11400 mm). Average annual rainfall of the district is above 4800 mm, with about 65% of it being received during the monsoon months (June to Oct) each year. The temperature fluctuates from 4°C during winter to 28°C during summer. The district's soils range in texture from light to heavy and have a strong to moderate in soil reaction (pH: 4.0 to 5.1). Soils are high in dichromate oxidizable organic carbon content (>1.8 to 2.2%), medium to high in available nitrogen, but low in phosphorus and potash content. The district is a hub for the state's vegetable growing regions. The crops grown are diverse, and they range from cereals (rice, maize), spices, to various types of vegetables and fruit trees. Lowland rice grows in Intermontane valleys, while in sloping uplands, spices (turmeric and ginger), vegetables (potato, tomatoes, cauliflower, radish, carrots, peas, capsicum, sweet potatoes, etc.), and fruit trees (pineapple, pear, guava, etc.) are grown.

Data Collection

The study took place in a region where traditional farming methods are predominant in one of the most intensive vegetable, and spice growing areas of Meghalaya. Several representative high-altitude (>1500 m MSL) remote villages with mild to very steep slopes (>45%) were the part of the study. Extensive field surveys, personal rural appraisals (PRAs), interviews, semi-structured interview schedules, focus group discussion, and observation methods were used to collect information on the widespread use of ITKs in farming, natural resource conservation (soil and water), and post-harvest storage of produce. Nearly 300 farmers were selected, PRAs were conducted and interviewed using questionnaires that contained information on the cropping system, ICAR / state government intervention, traditional agricultural practices, including SWC, rainwater harvesting, and post-harvest storage to analyse the sustainability of traditional practices (Photo 1).

The respondents comprised both male and female farmers from different age groups in the district. In order to obtain reliable and meaningful information on ITKs with

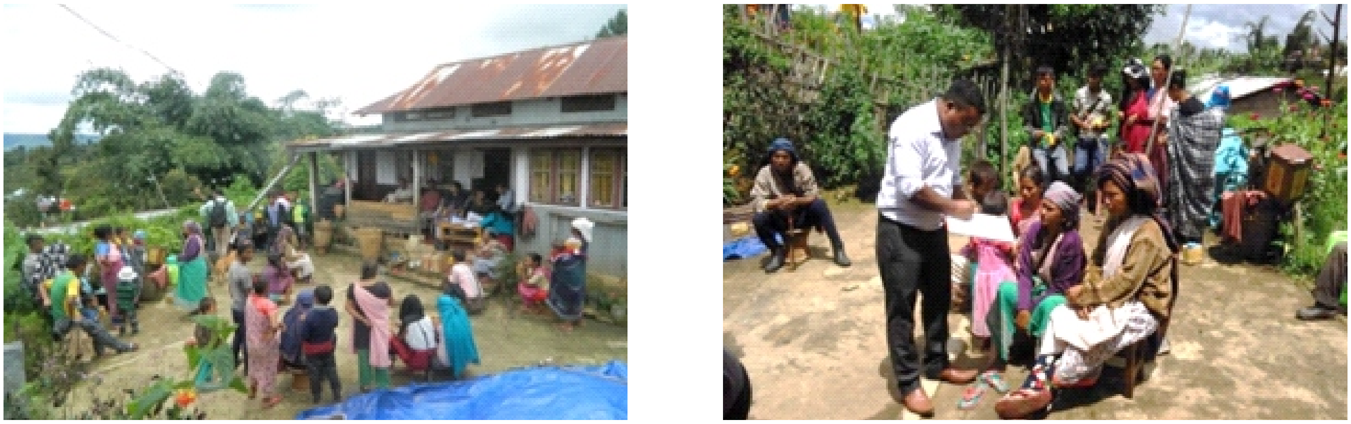

Photo 1. Participatory rural appraisal conducted at the villages

the utmost care, we chose to use personally on-field observation and visualization as the final tool. Crop-cutting methods were employed to gather yield-related parameters for different crops that were prevalent in the area. The scientific literature provides support for the presentation and discussion of photographs of prominent systems / activities captured during field visits and observations.

3. RESULTS AND DISCUSSION

The survey's findings, as well as supporting documents and literature, are presented in this section. We have observed that a considerable number of farmers have switched to settled agriculture from traditional shifting cultivation in the past few decades. The change resulted in the adoption of different indigenous farming methods based on the local topography and environmental conditions, which were either developed on their own or inherited over generations. This was helping them conserve soil and water resources in a sustainable manner. The most popular and widely used ITKs in the surveyed districts are presented and discussed below:-

Traditional Methods of Rainwater Harvesting

Despite the fact that the study area is home to the world's highest rainfall receiving zone (Cherrapunji plateau: > 11500 mm annually), it faces a serious problem of water scarcity, especially in the months following the monsoon (Nov to March). Improved rainwater harvesting technology has been developed in recent years, but their adaptability to the farmers' fields in the region is extremely low (10%). The undulating topography with steep slopes and faulty land use practices cause severe runoff and soil erosion, resulting in an annual average soil loss exceeding 50 Mg ha^{-1} (Choudhury *et al.,* 2022). Siltation, contamination of water bodies, and flooding of downstream catchment areas occur frequently in the region.

The farmers in the region are not willing to embrace improved technologies, as previously stated. To solve the water scarcity problem, they utilize their age-old indigenous method of rainwater harvesting systems to meet water requirements for drinking, domestic use, livestock, and irrigation. Rooftop rainwater harvesting (Photo 2a), an indigenous and simple method of rainwater harvesting during monsoon months has been in practice for decades by most households in the region. Rainwater from rooftops is collected using an iron (or galvanized) sheet and stored in a barrel or sintex tank for future use. Before being stored in the tank, they filter the water using a cotton cloth tied at the end of the collector pipe to remove residues, turbidity, and colour. The size of water collecting barrels or sintex tanks is determined by the needs or water requirements of farmers. Farmers overcome water scarcity for almost six months by utilizing this water harvesting system. The construction, operation, and maintenance of these are both less expensive and easier. In the steep hilly terrain of the region, farmers avoid transporting water in small buckets from distant water sources and perennial streams located far-reach downstream. Water erosion is reduced in urban areas, and this method of water harvesting is highly preferred in hilly and dry areas, especially in villages across Meghalaya.

The marginal farmers of Meghalaya have developed and practiced their own low-cost traditional system of water harvesting, *i.e.* bamboo baskets shaped like a silo for storing grains. Farmers construct a small tank-like structure using a polythene sheet and a wooden structure made of bamboo or pine wood logs lined externally in all corners (Photo 2b&c). In addition to the raindrops that fall directly, the rainwater from rooftops is also collected and stored in this structure for future domestic uses. The tank's top is covered with plastic to prevent evapotranspiration and algal growth. The dimensions of this system are approximately 3.0-4.0 feet tall and 1.0-2.0 feet wide, allowing farmers to store approximately 200 to 250 litres of water. The approximate cost is about ₹ 150 to 200, including sheet and wooden supporting structures. The water that is collected is used domestic use including washing farm produce. The

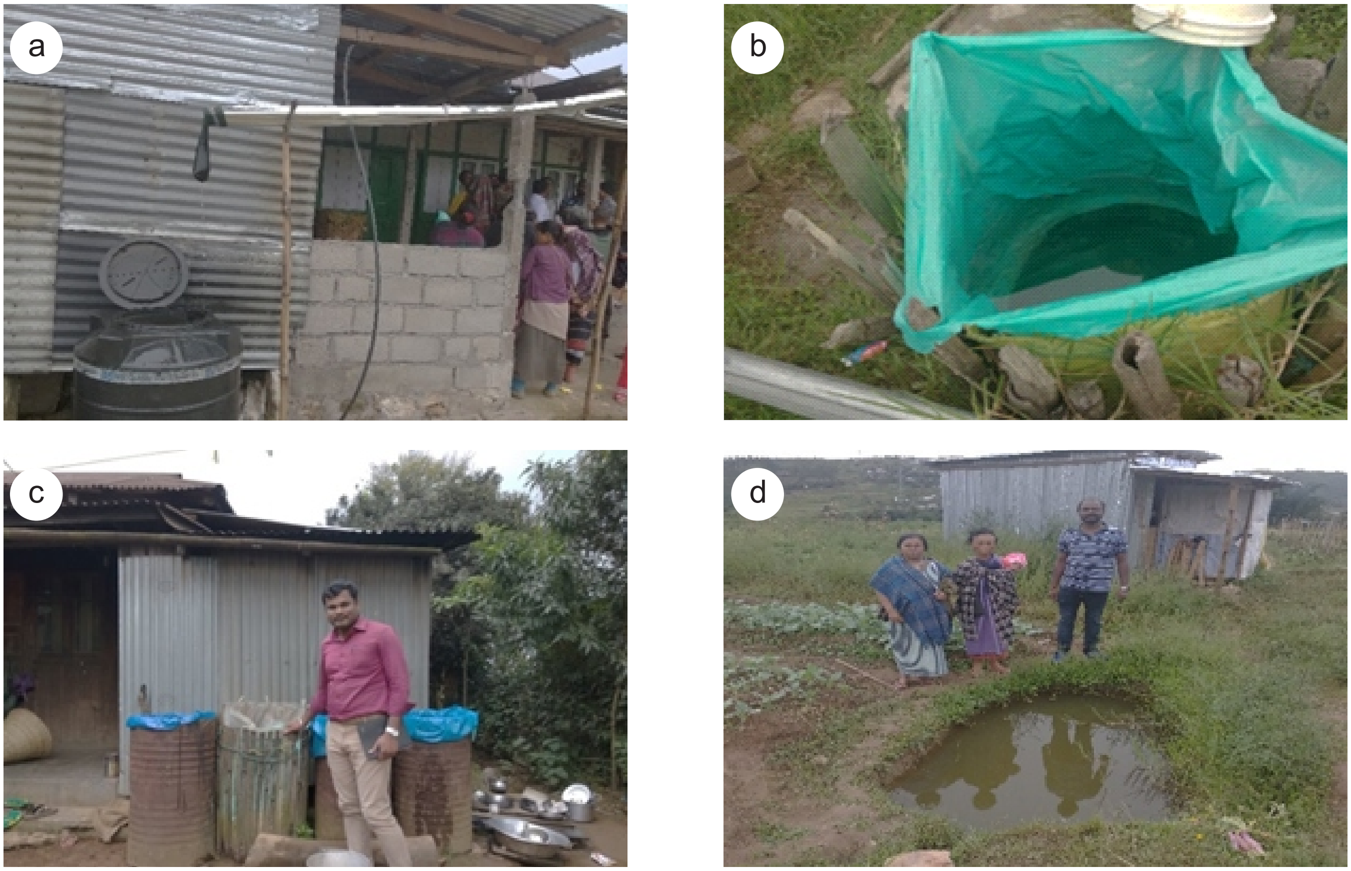

Photo 2. Rainwater harvesting using indigenous traditional methods

Table:1
Comparison of different ITK water harvesting methods practiced by farmers

Parameters	Rooftop	Pit method	Low-cost polythene vertical tunnel
Material for construction	GI / iron sheet for collecting rainwater, pipe for carrying it and storage drum / sintex	The only requirement is to dig a pit	Wooden logs (Bamboo / Pinewood / others) and plastic sheets
Construction costs (INR)	5000-7000	500-1000	200-250
Water storage capacity (litres, L)	500-1000 L storage tanks are typically used by farmers based on their house and rooftop area.	500-1500 L	200-250 L
Usage	Drinking water, domestic use, pig rearing, crop water demand and agricultural produce washing.	To meet crop water demand and wash agricultural produce	Domestic use

traditional water harvesting system solves the water scarcity problem during lean periods which spread over six months in a year.

Another traditional method used by farmers is to harvest rainwater through the pits (Photo 2d). During the monsoon season, farmers dug pits of varying sizes based on their land availability, water requirements, and field location. Pits are typically constructed with a length of 4-6 feet, a width of 2-3 feet, and a depth of 2-2.5 feet. Approximately 1500 to 2000 litres of rainwater can be stored in a pit that has a length of 6 feet, a width of 3 feet, and a depth of 3 feet. They use this stored water for life saving irrigation and wash their economic produce. The pits collect rainwater and replenish groundwater, recharging underground aquifers. The water percolates more slowly than in the open well because there is no hydrostatic pressure in the recharge pits. Recharge pits are constructed near kitchen gardens in farmers' houses or agricultural land. GI or plastic pipes are used to divert rainwater from rooftops into pits for storage and future use. Different traditional water harvesting methods practices by farmers of Meghalaya are presented in Table 1.

Nur-bun Method of Cultivation and Soil Erosion Minimization

The *Nur-bun* is a traditional method of growing various root crops and vegetables on steep slopes in Meghalaya due to its high rainfall, undulating terrains, and sloping uplands. In the local Khasi language, the word *'Bun'* means an agricultural land unit and denotes one raised bed, while the word *'Nur'* refers to a furrow that allows excess rainwater to flow without damaging the *Bun*. In the *Nur-bun* method, raised beds are made to a height of 0.50 to 0.70 m, 1 to 1.25 m in width, and a convenient length (usually 2 to 7 m) with a gap of 0.5 to 0.7 m between the beds (Photo 3) (Kharumnuid *et al*., 2018; Savita *et al.,* 2019).

The primary purpose of this method is to cultivate root and tuber crops, such as carrot, potato, sweet potato, ginger, and turmeric. This method overcomes soil compactness and water stagnation during the rainy season (June-Sept). It makes the soil light, friable, and porous, facilitating infiltration and downward movement of water, making it easy for roots/below ground economic parts to penetrate. The overland flow velocity, runoff, and soil erosion can be reduced by properly covering the ground surface with crop covers. This method produces crops that reach remarkably larger sizes, which result in higher returns in the market. After making the *Nur*, farmers used to make several pits 10-15 cm deep and 10 cm wide in a row on the raised bed. The pits are filled with materials such as weed biomass/organic

Photo 3. Step-wise *Nur-bun* method of cultivation

manure (primarily poultry or farmyard /pig manure) in a sequence. Finally, the pits are covered with dug-out soil and seed/seedlings are placed in the centre. The use of this technique is advantageous because it releases the carbon and nutrients stored in the weed/leaf biomass slowly upon mineralization and keeps them in the root zone, thereby minimizing nutrient losses through runoff. This results in better soil aggregation and optimal hydrothermal regimes in high altitude mediated low temperature zone. The result is improved soil quality and increased crop productivity. The addition of manures below the surface in pits also reduces the leaching of nutrients from the soil by acting as buffering agents. Soil moisture conservation is an added advantage as it influences the microclimate around the pit in the *Nur*.

Preventing Runoff and Soil Erosion while Cultivating Crops on Slopes

Over the years, farmers in these regions have developed and practiced growing vegetables along the slope in a zig-zag *Nur* and *Bun* system. The *buns* are made by arranging the leftover crop residues and weed biomass in a parallel row on the slope, which is partially covered with mud and burned. The partial combustion of biomass is aided by this activity. *Buns* (raised beds) are made with the same configuration as described earlier (Savita *et al*., 2019) but in a zig-zag pattern, with one end being the starting point for furrows of the next *bun* all along the slopes (Photo 4). This reduces the velocity of the runoff water and sediment loss while improving infiltration and downward percolation to store more water.

Biomass Mulching and Preventing Soil Erosion

Farmers in gentle to moderate slopes (20%) construct raised beds to a height of 0.50 to 0.60 m, a width of 1.0-1.25 m, and a length of 3-4 m. Rhizomes of turmeric or ginger and seeds/seedlings of vegetable crops (broccoli, cabbage, cauliflower, potato, etc.) are sown or transplanted on beds. The surface of the beds is covered with weed biomasses / crop residues / rice straw once the seedlings are established (Photo 5). By reducing the weed growth (by 45-50%) while covering the surface, evaporation and unproductive transpiration losses. Additionally, increase in hydraulic conductivity in the upper 30-cm depth by >15% results in an increase in profile moisture recharges (7-11%, weight basis) up to a depth of 45 cm (Choudhury, 2023). The control of soil erosion, particularly the splash caused by rainwater, is effective. The productivity of vegetable crops in beds with mulching increases by 35-71%, while the productivity of spices increases by 2-fold compared to non-mulched beds. According to the Institute KVK (Umiam, Meghalaya), the

Photo 4. Vegetable cultivation in a zig-zag *Nur-bun* (raised bed and furrow) system along the slope

Maize stover mulching in turmeric

Ginger crop after mulching with paddy straw

Paddy straw mulching in broccoli

Mulching in cabbage

Photo 5. Biomass mulching in spices and vegetable crops

income of the adopted vegetable farmers increased from 2.4 to 2.8-fold due to the use of mulching in cultivation practices.

Traditional Methods of Intercropping and Soil Moisture Conservation

Cultivation of chillies in barren rocky soil

During the rainy season, the sloping uplands of Meghalaya are highly susceptible to water erosion, and most of the top fertile soil is washed away during high-intensity rainfall events (Choudhury *et al*., 2022). The fine soil particles are washed away by the high intensity rainfall event, exposing gravel, stones, etc. The loss of soil and nutrients is also a result of such events. The challenge of working in rocky soils makes cultivating crops problematic. In addition, rocky soils lack nutrients, water holding capacity, compactness, and hinder root penetration. Farmers are cultivating crops like chillies that perform best in rocky soil by practicing a system of planting over time based on experience and wisdom. A small pit is made at a depth of 10-15 cm, where weed residues/poultry manure are applied and seedlings are planted (Photo 6). Their belief is that making small pits and utilizing organic manure creates micro water harvesting structure that enhances the soil's water-holding capacity as well as improving crop performance by providing nutrients from organic manures or weed residues.

Turmeric-colocasia intercropping

Turmeric is cultivated in many parts of Meghalaya as a significant remunerative crop. The production of 16,324 tons (productivity of 6.0 t ha^{-1}) is achieved by cultivating it annually over an area of 2,577 ha. The lakadong turmeric variety is the most popular among tribal farmers in Meghalaya, with it is occupying 50% of the turmeric grown area. Lakadong's popularity is based on its ability to fetch a high market price due to its high content of curcumin (6.0-7.5%), which is about two times higher than other turmeric varieties available in the markets. The farmers of Meghalaya employ an indigenous method of inter-cropping Colocasia with turmeric as the primary crop (Photo 7). Colocasia is a herbaceous perennial plant that grows to 2-4 feet tall, with both leaves and corm used for edible purposes. The corm develops to a size of between 0.9 and 2.0 kg. By reducing the direct impact of raindrops, the canopies


Photo 6. Chili cultivation in barren rocky soil

Photo 7. Turmeric - colocasia intercropping

provided by both crops help prevent splash and sheet erosions while prevents evaporation losses in the field. Employing this indigenous method of inter cropping, they earn an extra income from the intercrop (colocasia). The main crop turmeric gets ready to harvest after ten to eleven months, while colocasia takes five to six months to harvest.

Maize-pumpkin intercropping

Vegetables and cereal crops are mixed together by farmers in the surveyed villages, with pumpkin being a mixed crop in the maize field. Farmers in the indigenous method select one tall; erect cereal as the main crop (maize) and a soil trailing crop (pumpkin) as a mixed crop (Photo 8). They make use of the available space between the maize crops to cultivate pumpkins. In the region, farmers do not follow a specific spacing for mixed crops, resulting in pumpkin trails on the soil throughout the field. Farmers cultivate a mixture of pumpkins and maize because it can tolerate shade, very low temperatures in high altitudes, and quickly cover the soil. In maize fields, pumpkin acts as living mulch, protects the soil from direct rain impact, and suppresses weed growth through its creeping growth habit (Dolijanovic *et al*., 2015). Pumpkins' ground covering and fibrous root systems prevent the flow of runoff water, resulting in the retention of more moisture, detached sediments within the field, and a reduction in soil erosion. Ground surface cover reduces evaporation loss while allowing moisture to remain in the soil for longer duration to meet crop demands. Both crops have the same duration, but farmers receive extra benefits in terms of vegetables for personal and market consumption. Farmers used to dry pumpkin fruits under the sun to reduce their moisture content and prevent microbe growth, enabling them to be stored for a longer period since they are perishable. The cultivation of maize and pumpkin together has a greater


Photo 8. Maize - pumpkin inter cropping

yield advantage because of the improved utilization of natural resources, improved soil moisture conservation, reduced soil erosion, and a decrease in pests and disease incidence as compared to sole crops. In addition, it generates extra income and provides an additional food / nutrition source.

Ginger-sweet potato intercropping

The ginger-sweet potato intercropping system is one of the important indigenous intercropping that Meghalaya farmers follow (Photo 9 a, b). While ginger is a long-term crop (11-12 months), while sweet potato takes 3-6 months to harvest. The cultivation of sweet potatoes has several advantages, including high yield, high profit, and resistant to dry weather. They use it for personal consumption and livestock feed. The leaves, stems, and roots of sweet potatoes are used for different purposes. Another important benefit of sweet potato cultivation is that it acts as a cover crop in bare furrows, which can prevent soil erosion. The field is prone to water erosion due to the ginger plant architecture, which includes less foliage and a weak tap / fibrous root system proliferation. The cultivation of sweet potato as an intercrop in ginger fields overcome this shortfall and indirectly conserve soil and water resources by stopping the free flow of runoff.

Ginger-capsicum intercropping

Capsicum, one of the most important cash crops, is grown by most farmers in Meghalaya. The process of transplanting capsicum is usually made with ginger planting from April to May. Farmers used to earn a mid-term income by intercropping capsicum with ginger, as capsicum starts producing fruit in the second month and can continue for up to four months if kept in good condition. In addition to the primary ginger crop, they generate extra income by growing capsicum (Photo 10). Farmers remove weeds during intercultural operations and place them in the furrows between the bunds. By placing the weed biomass in the furrows, velocity of runoff water is reduced and soil and nutrient loss by erosion is decreased. Decomposition of weed residues also enhances soil fertility. The cultivation of ginger and capsicum as an intercrop in *buns* can help control pests and diseases and maximize the use of land, light, energy, nutrients, and water resources. Including capsicum as an intercrop in ginger cultivation has dual advantages in preventing infestations by nematodes (*Meloidogyne* sp. and *Pratylenchus* sp.) on ginger and capsicum, since these two nematode problems are major concerns in the cultivation of ginger and capsicum worldwide (Sharma and Bajaj, 1998).

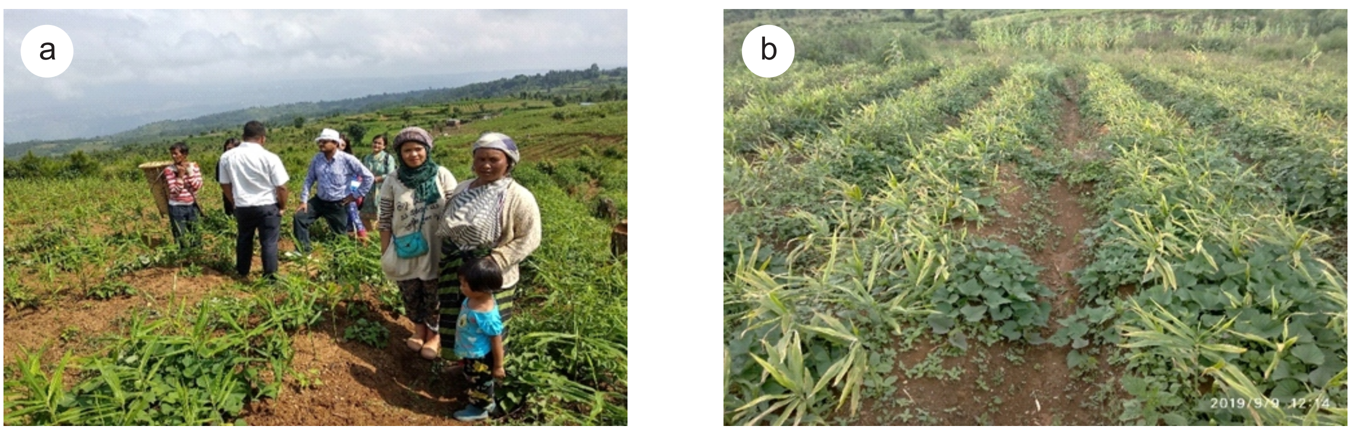

Photo 9a, b. Ginger - sweet potato intercropping

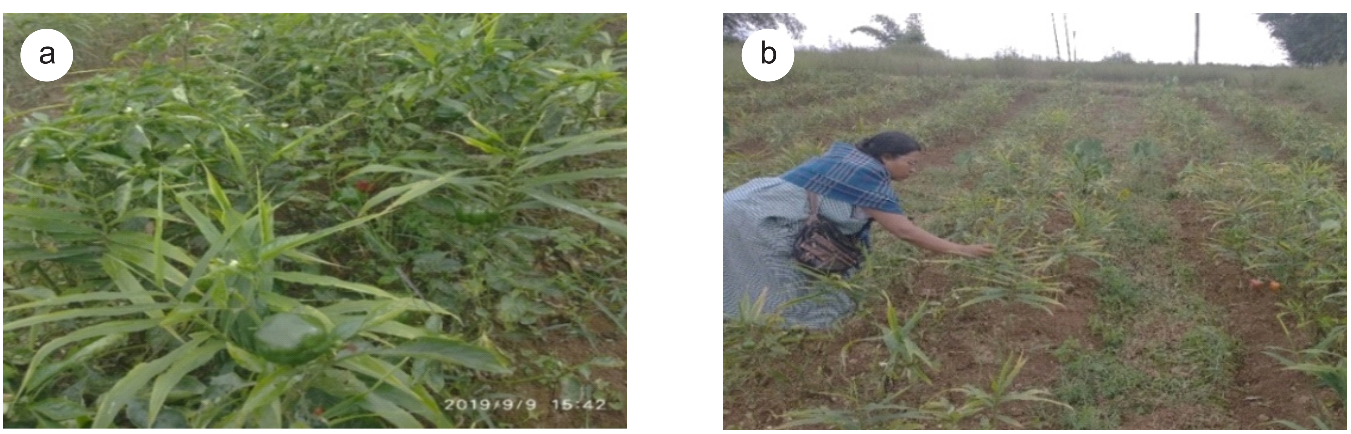

Photo 10. Ginger - capsicum intercropping

Pineapple-beans Intercropping

Pineapple is one of the most important fruit crops in Meghalaya, accounting for approximately 8% of the total pineapple production in India. The pineapple cultivation area has grown from 9808 ha in 2007-08 to 11314 ha in 2013-14 (Statistical Handbook, 2013). Despite its high economic returns, pineapple is a one-year-duration crop and its monochrome cultivation hinders the source of income. Small farmers are the dominant group and rely on a single enterprise as their main source of income. Without any other income during the pineapple cultivation period, they struggle to meet the basic needs of their daily life. Over the period, farmers in the region developed intercropping pineapple with short-duration intercrops of economic interest as an alternative source of income. This also helps them maximize the use of environmental resources and labour, in order to ensure the sustainability of farmers' families (van Asten *et al.,* 2011). Pulse crops, particularly beans, are used as intercrops in pineapple plantations by farmers in the region because pineapple is planted in rows with enough space for intercrop cultivation (Photo 11). By intercropping pineapple with leguminous crops, the available space and resources are utilized, as well as soil fertility is improved through biological nitrogen fixation, soil structure improvement, and soil organic matter addition through the decomposition of fallen leaves and post-harvest crop residues. This improves soil health, better aggregation, and resistance to soil erosion in the slopping uplands, while improving the yield and quality of pineapple fruit and extra income generation. Intercropping pineapple with pulse crops such as cow pea and beans can result in the production of allelopathic chemicals, which can suppress plant pathogens, including plant-parasitic nematodes and pests. By increasing soil organic matter and temporarily eliminating soil micro-biostasis after incorporation of crop residues of the intercrop into the soil, this enhances antagonistic microorganisms and provides a favourable environment for microbial activity (Muller and Gooch, 1982; Hooks and Johnson, 2002; Wang *et al*., 2003). Due to the pineapple's poor foliage cover and the wide spacing in common practices, the bare soil surface along the slopes is subjected to soil erosion. As a result, the region's soil erosion is exacerbated by the use of sole pineapple cultivation practices in the hills, and the annual soil loss can exceed 80 Mg ha^{-1} (Choudhury *et al*., 2022). The use of beans as intercrops on exposed soil surfaces acts as cover crops to suppress weed populations and prevent soil erosion and sediment loss. In addition, farmers perform weeding twice when pineapple is grown as a single crop, but they only perform it once in every two months when grown as an intercrop. This reduces production costs by reducing man hours in the cultivation process.

Photo 11. Pineapple-beans intercropping

System productivity improvement in the traditional cropping system practices

The profitability of maize-based, ginger-based, turmeric, and pineapple cropping systems in Meghalaya was determined by calculating their system productivity (Table 2). System productivity was higher for almost all intercropping systems compared to solo cropping systems. Ginger-capsicum intercropping systems achieved the highest system productivity, followed by turmeric-colocasia inter-cropping systems. Intercropping successfully reduced the risk of crop failure under this highly erratic rainfall scenario, in addition to yielding more monetary benefits and higher system productivity. Adaptability to strong soil acidity-induced fertility stress, moisture-induced abiotic stress, and high humidity-led biotic stress from pest and disease infestations is also increased.

Table:2
System productivity of different indigenous intercropping systems practiced by farmers of Meghalaya

Intercropping	Yield of main crop (kg ha^{-1})	Present market rate (₹)	Yield of intercrop (kg ha^{-1})	Present market rate (₹)	Income from the main crop (₹)	Income from intercrop (₹)	System productivity (₹)
Nur method of cultivation							
Turmeric- colocasia	7350	40	13224	20	294000	264480	558480
Maize - pumpkin	2262	20	12448	20	45240	248960	294200
Maize - carrot	2262	20	19452	20	45240	389040	434280
Ginger - sweet potato	7254	50	3985	15	362700	59775	422475
Ginger - capsicum	7254	50	9008	60	362700	540480	903180
Pineapple - beans	12004	15	6742	40	180060	269680	449740

Traditional ways of intercropping in these hilly uplands have the following advantages: (i) it helps to reduce the direct impact of raindrops, prevents the loss of top-fertilized soil from erosion, and control weeds, (ii) the farmer's family's sustainability is supported by the addition of supplementary income and more nutritional diversity and security compared to sole cropping, (iii) it is a type of insurance when the main crop fails, (iv) by intercropping, shade is provided and the main crop is supported, while soil fertility is improved, and (v) it facilitates no competition between the intercrops while increasing cropping intensity and diversification per unit of agricultural land (Choudhury *et al.,* 2023). The productivity of land resources in limited availability can be improved by doing this.

Farmers' feedback on the major issues of hill farming

The availability of good quality water for drinking and agricultural activities is a major concern, as shown by interactions with rural farmers. Water scarcity is a primary constraint despite the abundance of rainfall every year. The lack of large-scale rainwater harvesting and storage strategies was acknowledged by farmers as the reason. Farmers are well aware of the importance of conserving soil and water resources, and they have been practicing it in their traditional ways at household scale over the ages. During village visits, scientists witnessed the same thing, where most of the residents installed traditional rainwater harvesting systems in their homes. Hill farming is facing another significant obstacle because of the lack of quality planting materials and marketing facilities for selling the produce. Farmers frequently purchase plant materials from nearby markets and are unaware of their quality until they begin growing them in their field. Other sources are from the previous season's crops or borrowed from fellow farmers whenever possible. One of the most common challenges faced by resource-poor farmers in our country, and north-eastern India in particular, is marketing their produce and obtaining a remunerative price. The prosperity of farmers is impacted by the way intermediaries earn more profits than growers. Many farmers are reluctant to take measures to control pests and diseases and are sometimes hesitant to harvest their produce (*e.g.* tomatoes) because of the lower price quoted by intermediaries. The glut in the market is caused by the production of specific perishable crops during small harvest windows, while the lack of cold storage facilities forces them to leave their produce in the field, it becomes waste. Tomatoes are sold by growers at a rate of ₹ 8 kg^{-1} to middlemen, while the price of tomatoes in the market is ₹ 50-80 kg^{-1}. Thus, middlemen get 5-8 times more profit in just 2-3 days than farmers who grow tomatoes for 5-6 months with great difficulties. Growing crops is a challenge for them due to the undulating rain fed upland, which can lead to crop failure due to erratic rainfall occurrences. In addition, the unavailability and ever-increasing cost of inputs such as seeds, seedlings, fertilizers, and manures lead to high costs of production. Furthermore, the lack of organized and accessible marketing facilities further compounded their hardships due to the low remuneration of their products.

4. CONCLUSIONS

This comprehensive study revealed that mountain ecosystems experience soil erosion during monsoons, and water shortage during post-monsoon months, even with abundant rainfall, is a major obstacle to agricultural development. Hill farmers argued that the absence of large-scale rainwater harvesting and storage strategies is to blame. Nevertheless, using their traditional methods such as rooftop rainwater harvesting, bamboo baskets, soil pits that can hold 50 to 60 cubic feet, and so forth, on an individual household scale, rainwater from 1500 to 200 liters can be stored to meet their essential water requirements. Similarly, using age-old traditional intercropping of maize-pumpkin, ginger-sweet potato, ginger-capsicum, and pineapple-beans, they are able to reduce soil erosion while storing in-situ runoff water in the pits or furrows. By doing this, they managed to increase the use of land, light, energy, nutrients, and water resources while also doubling system productivity, income generation, and livelihood security. The ginger-capsicum based cropping system was highly profitable and conserved soil and water resources in a hilly agro-ecosystem. These eco-friendly, simple and frugal indigenous resource conservation (soil and water) and hill farming (agronomic production and livelihood security) methods can be made popular on a large scale with the help of adequate location-specific scientific validation and need-based refinement to sustain mountain agro-ecosystems, including livelihood security, particularly for mountain farmers in the Himalayan ecosystem.

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