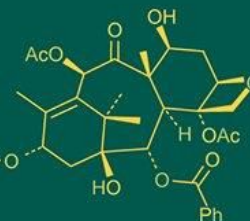
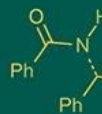
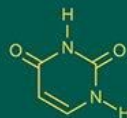
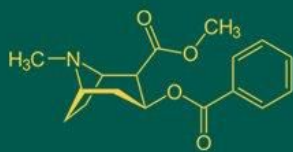


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Low-cost farming solutions for small and marginal farmers in hilly regions

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Abstract

Agriculture in India's hilly regions, including the Himalaya and North-Eastern states, is largely small-scale, labor-intensive, and based on mixed crop-livestock systems. Farmers contend with steep slopes, soil erosion, fragmented plots, water scarcity, climate variability, and limited infrastructure, all of which constrain productivity and income. Traditional practices-such as terrace farming, mixed cropping, and low-input organic methods-offer cost-effective, locally adapted ways to maintain soil fertility, conserve water, and ensure food security. Recent low-cost technological innovations, including bamboo-based drip irrigation, solar dryers, hermetic storage, small mechanization tools, and simplified polyhouses, have shown strong potential to boost yields, reduce post-harvest losses, and increase household income. Community-led initiatives, participatory seed systems, and digital advisory platforms further enhance adoption and resilience. This review draws on open-access studies and case examples from the Indian Himalayan and North-Eastern regions, highlighting key challenges, effective solutions, and pathways to scale sustainable, inclusive, and climate-resilient mountain agriculture.

Keywords: Marginal farmers, water harvesting, low cost solutions, sustainable farming, abiotic stress, organic

Introduction

In India's hilly regions like The Himalaya, the North-East and other hill ranges, agriculture is predominantly small-scale and family-based. Major population of small and marginal farmers who depend on mixed crop-livestock systems for food security and livelihoods is observed in these regions. These type of mountain farming systems provide dynamic ecosystem amenities like water regulation, biodiversity and cultural landscape but they run under severe biophysical and socio-economic limitations that slows down the productivity and returns^[1, 2].

Steep slopes, erosion-prone soils, terraced and limited arable lands make large-scale cultivation of crops difficult. Uneven rainfall, landslides, and climate change are further added to the list of risk to production in these delicate locations. Soil and water management, and controlling land degradation are some technical challenges that are seen across the Indian mountain zones and the broader Hindu Kush-Himalayan region^[2, 3].

Small and marginal hill farmers face structural barriers like poor rural infrastructure, limited market access, high input and transportation costs, limited institutional support, and large amounts of out-migration of youth that significantly reduces labor availability. These limitations show that modern technologies and large investments are often neither affordable nor appropriate for marginal farmers of hilly regions. Therefore, there is seen a growing importance towards low-cost solutions such as improved terrace management, low-cost protected cultivation like simplified polyhouses or low tunnels, rainwater harvesting and jalkunds, use of locally improved or short-duration varieties and organic nutrient management using vermicompost, compost which can raise incomes without imposing unsustainable costs. Evidence from Indian mountain states and regionally relevant studies shows these measures can be effective when combined with local knowledge, community institutions, and enabling policy support^[2, 4].

This review will synthesize the open-access literature and case studies relevant to Indian hilly regions to (a) map the major constraints faced by small and marginal mountain farmers; (b) evaluate low-cost technological, agronomic and institutional solutions that have been

tested or promoted in these contexts; and (c) identify knowledge gaps and policy actions needed to scale affordable, sustainable practices in mountain farming systems.

Challenges of Farming in Hilly Regions

Farmers of hilly areas face many challenges under the category of environmental, infrastructural, institutional, and socio-economical that makes farming in hilly regions difficult, risky, and low-profit. Below are some key challenges.

1. Physical and Environmental Constraints

- **Soil erosion, land degradation, and fertility loss:** Steep slopes, high rainfall intensity, and denuded vegetation cover lead to heavy soil and nutrient loss. For example, hills in Uttarakhand, initially have high organic matter but due to high erosion rates it causes decline in fertility and yields^[1, 2].
- **Fragmented lands and terraced topography:** Farmers in mountainous regions have small, neighboring plots, found on steep terraces. This limits the use of modern machines, advanced scale of operations, and cost-efficiency^[1].
- **Irregular and scare water supply:** Many Himalayan and Northeastern hill districts face seasonal drying during spring seasons and uneven rainfall, making water availability insecure during critical crop stages^[5].

Climate variability and change: Shifts in precipitation, temperature extremes, and unpredictable weather events (cloudbursts, landslides) increase risk. For example, in Sikkim Himalaya, ~88% of farmers reported climate change as a major challenge, alongside soil erosion and water instability^[6].

2. Infrastructure, Inputs, and Technology Constraints

- **Absence of irrigation structure:** Sharp terrains makes irrigation systems costly and difficult to maintain, leaving most farmers dependent on rain-fed agriculture^[1, 7].
- **High cost or inaccessibility of inputs:** Quality seeds, fertilizers, and equipment are often unavailable or unaffordable due to high transport costs and low economies of scale^[4, 8].
- **Inadequate storage, processing, and post-harvest facilities:** Absence of cold storage and processing facilities forces distress sales, causing post-harvest losses and low profitability^[2].
- **Poor physical infrastructure and market access:** Inadequate roads and weak market linkages increase transaction costs, making farmers reliant on middlemen^[2].
- **Limited technology adoption:** Mechanization is rare due to terrain, high costs, and lack of extension services^[1, 2].

3. Socio-economic, Institutional, and Policy Challenges

- **Small landholdings and labor constraints:** Fragmented holdings and youth outmigration reduce available labor, making farming costlier and less productive^[1, 6].
- **Financial constraints and credit access:** Farmers often lack collateral for formal credit, relying on high-interest informal loans that discourage investment^[4, 8].
- **Market volatility and weak bargaining power:** Perishable goods, price uncertainty, and lack of information often lead to distress selling^[4].
- **Institutional and policy neglect:** Many schemes and subsidies are designed for plain areas, overlooking the unique constraints of hilly regions^[7].
- **Social challenges:** Migration of younger generations erodes indigenous knowledge and leaves an aging population less able to adopt innovations^[1].

Traditional Knowledge and Indigenous Practices

Small and marginal farmers in hilly regions have relied for centuries on indigenous knowledge systems that integrate ecological balance, community participation, and resource conservation. These practices are often cost-effective, locally adapted, and sustainable compared to high-input modern farming. The three major pillars of traditional systems are:

1. Role of Age-Old Sustainable Farming Practices

Farmers in the Himalayan belt have traditionally recycled farmyard manure, used forest leaf litter as mulch, practiced seed-saving, and developed local soil and water conservation methods. Such practices preserve agro-biodiversity and ensure low-cost soil fertility management, though they are often labor-intensive and may yield less than intensive modern methods^[9].

2. Terrace Farming and Mixed Cropping

Terrace farming is one of the most characteristic practices in mountain agriculture, transforming steep slopes into cultivable steps. This method prevents soil erosion and enhances water retention, enabling cultivation in fragile landscapes^[9, 10]. In addition, mixed cropping systems like the traditional *Barahnaja* (cultivation of 12 or more crops together in Uttarakhand) provide food and nutritional security, spread production risks, and support soil conservation^[10].

3. Low-Input Organic Methods

The use of organic amendments such as compost, cow dung, and plant residues plays a critical role in maintaining soil fertility at low cost. Studies from the Sikkim and North Eastern Himalayas highlight that organic systems not only reduce dependency on external inputs but also improve soil microbial activity and resilience against climate variability^[11, 12].

Table 2: Indigenous and Traditional Farming Practices in Hilly Regions

Practice	Description	Benefits	Limitations	References
Age-old sustainable practices	Recycling of manures, leaf litter, and local soil conservation	Enhances biodiversity, sustains fertility, low cost	Labor-intensive, lower yields	[9]
Terrace farming	Step-like cultivation on slopes	Reduces erosion, increases water use efficiency	High labor & maintenance cost	[9, 10]
Mixed & inter-cropping (<i>Barahnaja</i>)	Cultivation of cereals, pulses, millets, and vegetables together	Nutritional security, risk spreading, soil cover	Difficult mechanization	[10]
Low-input organic methods	Farmyard manure, compost, bio-fertilizers	Improves soil health, low-cost input system	Lower short-term yields, knowledge intensive	[11, 12]

Low-Cost Technological Innovations

For hilly and resource-constrained farmers, high-cost technologies (like large-scale mechanization or industrial greenhouses) are often unaffordable and unsuitable for steep terrains. Instead, low-cost, locally adapted innovations have been developed and promoted by ICAR institutes, NGOs, and community-based programs to improve productivity, reduce drudgery, and ensure resilience against climatic shocks.

1. Low-Cost Polyhouses and Protected Cultivation

Polyhouses constructed with bamboo or locally available materials reduce input costs by 40–60% compared to commercial steel-based polyhouses. These structures allow off-season vegetable production, protect crops from excessive rainfall and frost, and extend the growing season in hills. In Himachal Pradesh and Uttarakhand, low-cost polyhouses have improved farmer incomes through the year-round cultivation of tomatoes, capsicum, and cucumbers^[1, 7].

2. Water Harvesting and Drip Irrigation

Rainwater harvesting tanks, lined ponds, and rooftop collection systems help overcome the seasonal water scarcity prevalent in Himalayan areas. When combined with low-cost drip irrigation kits, farmers reduce water use by up to 50% while maintaining or even improving yields^[1, 6]. These systems are particularly useful on fragmented terraces where traditional canal irrigation is not feasible.

3. Solar Dryers and Post-Harvest Technologies

Solar dryers constructed from locally available materials (for example simple wooden/bamboo frames plus UV-stabilized polyethylene or cabinet designs) are proving highly effective in mountain contexts. Compared with open-sun drying, low-cost solar dryers reduce drying time, improve hygienic quality, and cut post-harvest losses - making value addition feasible for smallholders and women-led groups in Himalayan communities. Field and prototype studies of handmade and cabinet solar dryers show they can be built cheaply, speed up drying, preserve product quality, and are appropriate for village-level adoption. In Uttarakhand and the eastern Himalayas, solar drying and fruit processing support value addition and circular economy linkages, opening up livelihood opportunities for women and farmer cooperatives^[13, 14].

4. Small Farm Tools and Mechanization Aids

Farmers in hilly regions use **improved hand tools** such as lightweight weeders, sickles, and low-cost power tillers adapted to terraces. These innovations reduce drudgery, especially for women farmers, and increase labor efficiency without the need for large tractors or machines unsuitable for slopes^[15].

Government policies and institutional support

Strengthen local, interpersonal extension. Farmers in Uttarakhand prefer and trust face-to-face sources (extension agents, farmer groups) over mass/digital media; policy must fund local extension staff, seasonal field schools, and community demonstration plots rather than relying only on mass/digital campaigns^[16].

Strengthen local, interpersonal extension. A study in Uttarakhand shows that hill farmers depend heavily on

interpersonal sources (extension agents, farmer groups) for agricultural information; education, gender, and land size significantly affect how farmers search for and use extension media. This suggests policies should prioritize face-to-face extension and context-appropriate communication channels over mass media or generic digital outreach^[16].

Prioritize soil–water conservation and terrace rehabilitation in state plans. Eastern Himalayan studies show ongoing land degradation, high overland flow and erosion; hill policies should finance terrace repairs, spring/small-pond rejuvenation, and low-cost water harvesting to retain moisture and reduce risk^[17].

Mainstream climate-sensitive mountain policy. Scoping reviews of Himalayan ecosystem services highlight the rapid climate impacts on water, soils and crop suitability; institutional support must integrate climate foresight (spring protection, seasonal advisories, community seed banks) into all hill-targeted schemes^[8].

Use international/state guidance to tailor national schemes to hills. FAO and mountain-focused guidance stress that national programs must be adapted (smaller subsidy units, group eligibility, terrain-sensitive thresholds) so small/marginal hillholders can access benefits equitably^[1].

Soil and Water Conservation Measures

Soil and water conservation is critical for small and marginal farmers in hills. Below are low-cost measures with examples from open-access sources.

1. Contour Bunding and Bunding

Contour bunding (creating small embankments or bunds along contour lines) helps slow runoff, trap sediment, enhance moisture retention, and reduce erosion. In Nepal, contour bunding (using slashed vegetation and local materials) has been adopted by ethnic communities to improve soil moisture and productivity in sloping lands over mixed agroforestry use. This practice is low cost, uses local resources, and improves crop output over time^[8].

2. Use of Vegetative Barriers and Agroforestry

Vegetative barriers (grass strips, hedgerows) planted along contours or field edges help reduce surface runoff velocity and trap soil. Agroforestry systems add further benefits by stabilizing soils, adding organic matter, and diversifying farmer income. A study in the Shivalik foothills (Uttarakhand) assesses soil properties under predominant agroforestry systems and finds improved soil structure, higher organic carbon, and better moisture retention under agroforestry versus non-tree systems^[19].

3. Low-Cost Check Dams and Ponds

Check dams, percolation tanks, and farm ponds are affordable interventions that capture rainwater and recharge aquifers. In Garhkundar–Dabar, 45 check dams and 11 ponds increased groundwater availability, turning seasonal streams perennial and improving irrigation access. Crop productivity rose by 40–80% for soybean, wheat, and chickpea, while migration declined as agriculture became more viable^[20].

Improved Crop and Variety Selection

Choosing the right crop and variety is a fast, low-cost way to make hill farms more reliable. A good genotype - one that

fits local slope, soil and season length - can stabilise yields without expensive input.

1. Millets in the Eastern Himalayas: Yield, Traits & Stability

Three years of testing in the North-Eastern Himalayan foothills assessed many high-yielding and landrace kinds of little millet: foxtail millet, finger millet, barnyard millet, little millet, proso millet, and brown top millet.

Among the best performers, finger millet produced yields from 1.16 to 1.43 Mg/ha. Additionally examined root morphology and physio-chemical characteristics: more deeper roots, great root length density, superior nutrient absorption-qualities supporting drought resiliency and stability. Local landraces also showed promise; for example, finger millet types "Sikkim-1, Sikkim-2, Nagaland-1, Nagaland-2" had superior nutritional value (better protein content, micronutrients) along with steady yields.²¹

2. Buckwheat: Underutilized but promising pseudocereal

Buckwheat in the Eastern Himalaya can withstand several stresses: low moisture, acidic soils (very common in mid-hills), and brief growing windows. Good conditions yield for grains are about 15–18 q/ha (i.e., 1.5–1.8 Mg/ha); green biomass yields even greater. Certain genotypes (IC26591, IC377275, Himapriya, IC14890) do especially well; therefore, varietal choice is important. Buckwheat further offers the advantage of increasing availability of phosphorus in acidic soils via root exudates-that is, functional characteristics beyond yield^[22].

3. Traditional Grain Legumes in Uttarakhand: Diversity & Potential

Examination of conventional grain legumes in the Himalayan area of Uttarakhand finds great genetic variety and several under-used pulses.

Legumes such as Rajma (kidney bean), Lobia (black-eyed peas), Bhatt (black soybean), Gahat (horse gram), Naurangi (cowpea), Urad, Mung, Arhar/Tur (pigeonpea), Masoor (lentil) are used by local farmers. Since the majority of land is rainfed (85+%) and terraces are limited, pulses and millets-which are more tolerant of low moisture and variable soil conditions-are much depended upon by farmers^[23].

4. Abiotic Stress-Tolerant Varieties in India: Status & Gaps

For drought, heat, cold, waterlogging, salt etc., new kinds are being developed. Many are, however, tested under regulated or perfect circumstances; fewer are properly validated across many hill microclimates. Gaps: seed availability, farmer awareness, and cost of adoption (sometimes inputs required) are constraints. Also, breeding programs often focus on major crops; under-utilized crops are less attended^[24].

Post-Harvest and Value-Addition Solutions

Lack of simple value addition and post-harvest losses cut income from hill farms and drive perishable products toward waste. Little expenditures in low-cost storage, basic drying, and village-level processing can lock in value, increase shelf life, and generate new marketable goods.

Low-cost storage structures

Purdue Improved Crop Storage (PICS) bags and hermetic liners - triple-layer bags that keep oxygen low and prevent insect damage for months; widely shown to cut losses and protect the quality of grain^[25].

Efficient where households need longer storage and can afford little one-time expenses are improved jute polypropylene bags with liners (Grain Pro-like systems) and tiny metal or concrete mini-silos^[26].

Solar dryers for fruits and vegetables

Performance and design notes: Galvanized sheet low-cost tunnel/chimney dryers, timber, bamboo frames, and UV-stabilized polythene can cut drying time in half and minimize contamination with reference to open drying; field testing of some recent low-cost natural-convection tunnel designs reveals excellent economic and thermal efficiency^[27].

Socio-economic gains: community or cooperative solar dryers raise incomes by enabling off-season sales, improving product quality, and reducing losses; farmer acceptance rises when dryers are locally built, affordable, and paired with training^[28].

Village-level processing and value addition

Small, local processing facilities transform perishable or heavy items into higher-value, more readily storable products thereby raising farmer incomes and local employment.

Examples of low-cost value addition include small-scale milling, an oil expeller for oilseeds, solar-dried fruit-vegetable chips, jam/preserves, pickles, dehydrated herbs, basic sorting-grading and hygienic packaging for small batches. These call for little gear, fundamental sanitation education, and straightforward packaging^[29].

Extension & markets: value addition works best when combined with training (food safety, basic business skills), market linkage efforts (local fairs, institutional buyers), and packaging that meets local consumer expectations. Extension strategies strongly influence uptake^[30].

Case Studies of Successful Low-Cost Solutions

Given their work on small terraces, steep slopes, and weak soils, mountain farmers often see the finest returns (less capital, simpler upkeep, faster adoption) from affordable, locally repairable technologies and community models^[31].

Indian Himalayan Region (IHR)

Sikkim's terrace repair and intensification are doable and affordable.

In Sikkim basins, little investments in terrace rehabilitation-stone vegetative bunds, re-grading, and micro-plots-have enhanced soil retention and crop yields. Cost-benefit research reveal that low-cost vegetative obstacles used to fix and maintain terraces often help to compensate the cost within a year. few seasons: this makes terrace construction among the most affordable hill interventions^[31].

Across India-including hilly regions-farmers are increasingly turning to hermetic storage solutions such as PICS bags and small airtight containers. These systems greatly reduce losses from insects and mould, allowing grains to be stored safely for longer periods. Studies and field trials have shown that when farmers have access to

hermetic storage, they tend to keep their produce longer and sell it later at better prices. This simple, affordable technology offers a quick and effective way to preserve harvest quality and boost farm incomes^[32].

North-Eastern States

In Meghalaya, Khasi and Jaintia farmers have long practiced an ingenious and ultra-low-cost form of irrigation using bamboo drip systems. By channeling spring or stream water through gravity-fed bamboo pipes, they efficiently irrigate areca nut, betel leaf, and mixed orchards on steep slopes. The system relies entirely on locally available bamboo, requires minimal maintenance, and eliminates the need for pumps or costly infrastructure. It stands as a remarkable example of traditional knowledge offering a sustainable, high-impact solution for hill farming^[33].

Global best practices in mountain agriculture

Restoring and maintaining terraces through simple practices like repairing stone or vegetative bunds, de-silting channels, and planting cover crops along terrace risers helps keep the soil stable and productive. These measures significantly reduce erosion and sustain crop yields over time. Community-led or locally managed terrace upkeep has consistently proven to be one of the most cost-effective ways to preserve soil health and long-term productivity in mountain farming areas^[34].

Incorporating agroforestry and home-garden systems-where trees, shrubs, and multiple crop layers grow together-helps enhance both farm diversity and income. These systems supply farmers with fodder, fruits, and fuelwood while improving soil fertility, moisture retention, and the overall microclimate. By spreading production risks and supporting biodiversity, they create more resilient farms. Experiences from mountain regions such as the Himalaya, Andes, and Alps show that agroforestry can increase overall productivity per unit area while providing vital ecosystem benefits^[35].

Future Prospects and Recommendations

1) Scaling up affordable technologies

Scaling up affordable, locally suited technologies-like terrace repair, bamboo irrigation, solar dryers, hermetic bags, and small drip kits-is less about introducing a single large machine and more about building supportive systems. Success relies on local production and repair networks, hands-on demonstration plots, accessible financing, and collective ownership through self-help groups or cooperatives. Key practical steps include:

- Develop local supply chains by engaging small producers, masons, and carpenters to build and maintain solar dryers, frames, and bamboo irrigation channels, keeping both costs and downtime minimal^[36].
- Provide financing through microcredit, output-linked loans, or community pooling to reduce upfront costs for households, and complement this with targeted subsidies when needed^[37].

2) Role of digital tools and mobile advisory services

- Evidence from trials and reviews shows that digital advisory services boost farmer knowledge and prompt timely actions on fertilization and irrigation, often increasing yields-particularly when advice is localized,

actionable, and linked with on-the-ground extension support^[38].

- Digital platforms can connect farmers to market prices, buyer networks, and weather insurance, strengthening the economic incentives for adopting new practices. Success depends on maintaining data privacy, offering a simple user interface, and working through trusted local intermediaries^[39].

3) Roadmap for sustainable and inclusive development

- **Phase A:** Prepare (0–2 years): Identify vulnerable communities and pilot bundles of low-cost technologies-such as terrace repair, seed banks, and solar dryers. Establish 3–5 demonstration clusters and train local technicians. Ensure planning is participatory, actively involving women and youth in all steps^[40].
- **Phase B:** Expand (2–6 years): Grow successful pilot initiatives through local micro-enterprises and SHG co-op ownership of solar dryers and storage units. Integrate digital advisory services via SMS, IVR, or WhatsApp, and strengthen value-chain connections through collective marketing and small-scale cold chains. Provide supporting finance options such as microloans and output-linked contracts^[41].
- **Phase C:** Sustain & Mainstream (6+ years): Embed mountain-sensitive policies covering seed systems, subsidies for community assets, and standards for hermetic storage and dried products. Invest in renewable energy solutions for processing, such as solar dryers and micro-grids, and establish monitoring systems to track adoption, equity, and environmental impacts. Align all programs explicitly with SDG targets, including food security, climate resilience, and gender equality^[41].

Conclusion

India's mountain farming systems encounter unique biophysical and socioeconomic difficulties, such as labor shortages, water scarcity, restricted arable land, and steep, erosion-prone slopes. Traditional techniques like terrace farming, mixed cropping, and organic nutrient management provide long-lasting, low-cost solutions, but they may not be sufficient to satisfy today's production demands. Open-access research and regional case studies demonstrate that inexpensive technologies such as low-cost polyhouses, solar dryers, bamboo drip irrigation, hermetic storage, and minor mechanization equipment can be used to accomplish this increase productivity, lower post-harvest losses, and raise farmer incomes. Participatory demonstration plots, community or cooperative ownership, local supply chains, and available funding are all necessary for successful scaling. Digital advisory platforms are especially helpful when coupled with in-person. Additionally, the extension promotes timely decision-making and information exchange. A phased approach-preparation, expansion, and mainstreaming-integrating low-cost technologies, institutional backing, and climate-sensitive policies is essential for sustainable, inclusive, and resilient mountain agriculture. By giving priority to these measures, it is possible to improve food security, safeguard vulnerable ecosystems, and strengthen livelihoods in India's mountainous areas.

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