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Strategies for mitigation of moisture stress

in winter season crops in hilly ecosystem

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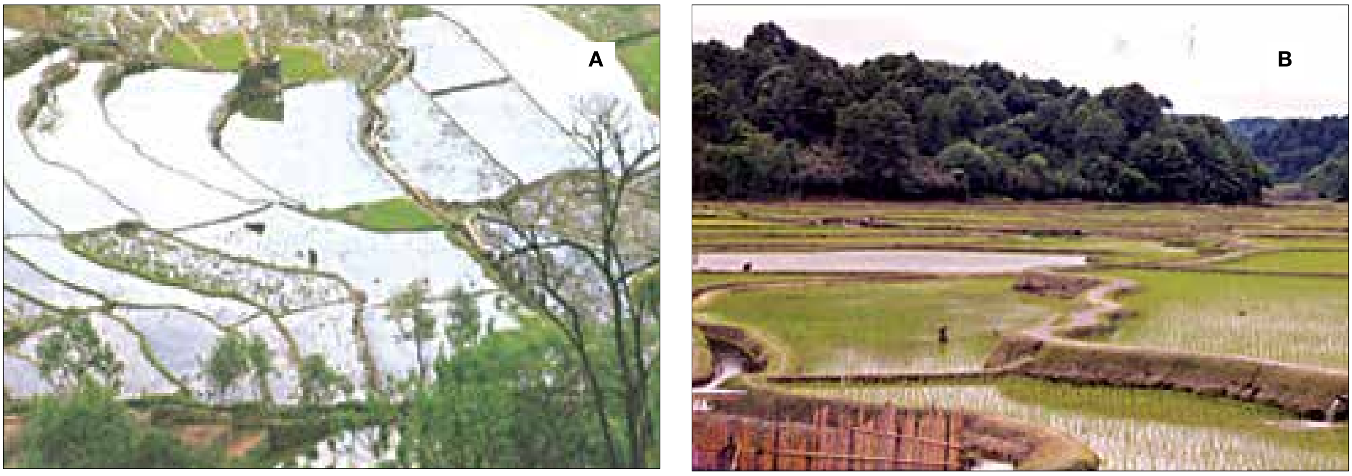
The hilly ecosystem of northeast India experiences significant moisture stress during the winter season due to its unique topography, erratic rainfall distribution, and limited water retention capacity of soils. Although the region receives high annual rainfall, over 70% of it occurs during the monsoon months, leading to dry winter conditions that severely affect the growth and yield of rabi crops. Traditionally, farmers of these region practice several water management practices like Panikheti, Apatani, Zabo, Bamboo irrigation system, etc. focusing the judicious use of rainwater. However, range of agronomic, structural, and technological strategies can be adopted to cope up with these challenges during winter season. Efficient water management techniques such as drip and sprinkler irrigation, along with rainwater harvesting systems i.e. Jalkunds, ensure optimal use of available water resources. Conservation practices like contour farming, mulching, and minimum tillage help retain soil moisture and reduce runoff. The use of short-duration crop varieties enhances crop survival and productivity under limited water conditions. Agroforestry and intercropping systems further improve soil structure and moisture conservation. Thus, adopting an integrated approach that combines traditional knowledge with modern scientific practices is crucial for effectively mitigating moisture stress in winter crops of hilly ecosystems. These strategies not only enhance crop productivity but also contribute to the long-term sustainability of hill agriculture in the region.

Keywords: Bamboo irrigation system, Drip irrigation, Sustainability, Water productivity

SOIL moisture is one of the key factors in influencing optimum plant growth, development and yield. Water maintains turgidity of plant cells, regulates stomata and drives photosynthesis. Even a 10–20% reduction in available water during critical growth stages can lead to yield losses of 30–50% in major crops like wheat and rice. Irrigation significantly boosts productivity. The hill ecosystem occupies 72% area of north eastern India, comprising of the states like Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. The North Eastern Hill (NEH) region of India exhibits a distinct dichotomy in its water cycle due to complex topography and climatic variability. The region hosts one of the highest annual rainfall receiving places in the world (e.g. Mawsynram near Cherrapunji receives about 12,000 mm/year). The rainfall over the region is more than sufficient for cultivation of *kharif* crops like rice, maize, vegetables like bhindi, capsicum, chillies, etc. However, as the rainwater gets drained off from hilly ecosystem, limited or no rainfall in *rabi* season leaves most part of these hilly region uncultivated due to moisture stress. Though, the region has a high groundwater potential, irrigation in crops becomes very expensive for marginal and small farmers. Thus, farmers practice mostly monocropping with rainfed *kharif* crops. With the available irrigation facilities, some farmers of the region cultivate crops like mustard, winter vegetable like cabbage, pea, cauliflower, potato, tomato, broccoli, knol-khol, etc. in some pockets. The water stress is the first and foremost challenge in the region for growing winter crops beside all other advantages like abundant land, fertile soils, favourable climate, rich biodiversity and high groundwater potential that supports the potential of the region for sustainable intensification. Therefore, development of farmer-friendly technologies for moisture conservation is the need of the hour for growing winter crops in these hilly ecosystems vis-à-vis increasing the cropping intensity as well as farmers' income.

Conservation tillage practices, such as minimum tillage and contour bunding, have been shown to reduce runoff by up to 40% and increase soil moisture



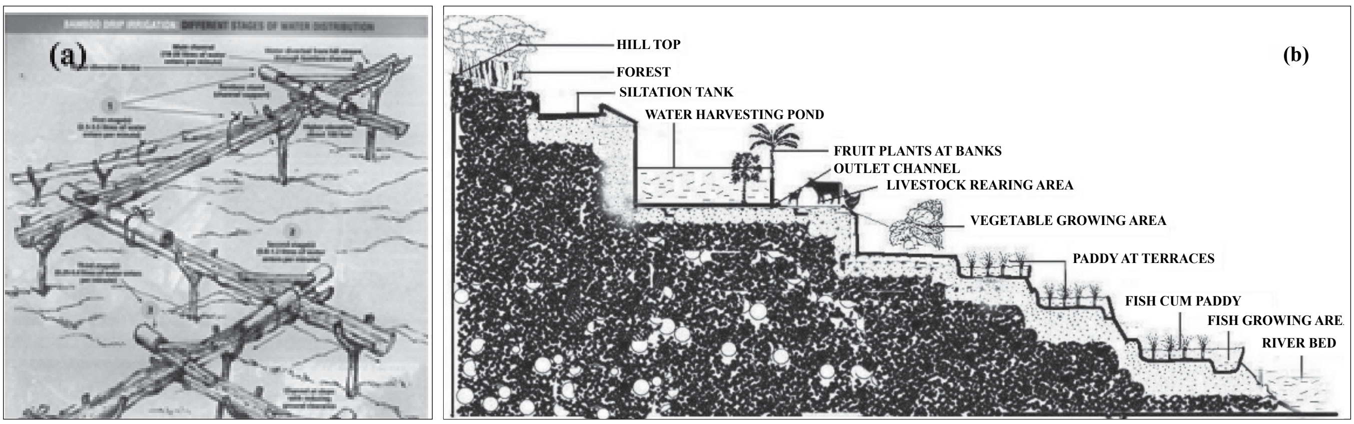
Panikheti (a) and *Apatani* (b) system of water management in northeast India (*Source:* Bundela 2007)

availability. Mulching with organic residues can decrease evaporation losses by 20–30% and improve soil temperature, promoting better root development. Use of short-duration and drought-tolerant varieties, intercropping, mixed cropping has enhanced yield stability under limited or excess moisture. Adoption of drip and sprinkler irrigation can improve water use efficiency by over 80% in vegetable crops grown on terraces. Rainwater harvesting through farm ponds and bamboo drip irrigation systems, traditional to the region, provide life-saving irrigation during critical growth stages. Together, these strategies form a sustainable framework to combat winter moisture stress and ensure food security in the hilly agro-ecosystems of northeast India.

Understanding moisture stress in winter season crops

The moisture stress during winter in crops is mostly caused by combined effect of no rainfall and high evaporation. Moreover, high hill slopes at the higher altitudes favours greater runoff and percolation losses. Moisture stress significantly affects crop growth and yield by limiting water availability for essential physiological processes like photosynthesis, nutrient uptake, etc. Prolonged drought conditions lead to reduced leaf area, stunted growth, and early senescence, ultimately decreasing biomass production. Yield losses occur due to lower grain filling, reduced seed size, and fewer reproductive structures. Crops under moisture stress also experience increased vulnerability to pests and diseases, further exacerbating yield decline. Moisture stress also negatively impacts soil health by reducing microbial activity, nutrient availability, and organic matter decomposition.

The farmers of these regions use indigenous technical knowledge to use the rain water judiciously during *kharif* seasons. These systems are very effective under hilly ecosystems of this region. Some of these systems are bamboo irrigation system, *Panikheti* system, *Zabo* system of Nagaland, *Apatani* system in Arunachal Pradesh, etc. In *Panikheti* system, water is diverted from upper terrace to lower terraces maintaining a desired water level to each terrace. These systems check erosion at high hill slopes and particularly suitable for rice cultivation. The integrated rice-fish farming in the terraces of Arunachal Pradesh is called *Apatani*. Here, stream water is supplied to rice fields through canals and the distant rice fields are connected to each other by draining pipes. In the bamboo irrigation system of Meghalaya, particularly practised in *Jaintia* hill district, farmers use to supply hill stream water from upper reaches through bamboo channels and irrigate arecanut and betelvine in the field particularly on steep hillslopes. *Zabo* system of farming typically consists of rainwater harvesting pond in the



Bamboo irrigation system (a) and *Zabo* (b) system of water management in northeast India
(*Source:* Bundela 2007, Singh *et al.* 2018)

steep hilly slopes, and application of harvested rainwater for agriculture, forestry and animal husbandry.

Farmer friendly strategies for mitigating moisture stress

Efficient soil and water conservation practices: Mitigating moisture stress in field conditions necessitates the need for conservation of *in situ* water resources. Maintaining adequate winter moisture supports critical crop growth stages like germination and tillering, ultimately leading to yield improvements of 15–35%. Ensuring water availability during these periods is thus essential for sustainable productivity. Here some of the farmers' friendly technologies are discussed.

- **Mulching:** The mulching with materials such as straw, crop residue, leaves, live plants, or plastic is most prominent strategy to conserve moisture *in situ* soil moisture, protect soil from erosion and improve fertility. Depending on climatic conditions, straw mulch can reduce evaporation by 70%, thereby significantly reduce the irrigation needs of crops. It also regulates soil temperature, suppress weed growth, and reduce evaporation, thereby promoting crop growth. Further, the decomposition of organic mulches enriches soil with nutrients and physical health.

Organic and plastic mulching in tomato

- **Contour farming and bench terracing:** Contour farming involves planting, and cultivating along the natural contours and across the slope of the land, which helps to slow down water runoff, reduce soil erosion, and enhance water infiltration in gentle to moderate slopy hilly terrains ranging from 2–10%, whereas, bench terracing involves converting steep slopes into a series of flat, step-like platforms (benches) particularly suitable for steep slopes of 16–33%. These practices can enhance moisture conservation by reducing runoff up to 50–60% and increasing water infiltration by 30–40%. Moreover, the soil moisture retention through these practices may be as high as 15–25%, leading to better crop performance in rainfed and hilly regions. Cover crop such as legumes (soybean, pea, groundnut, chickpea, lentil, etc.) are used widely besides non-legumes. The cover crops can retain soil moisture as high as 30% compared to bare soil, especially in dryland and rainfed systems. The dense canopy of cover crops acts as live mulches and significantly lowers evaporation rates. Additionally, the root systems of cover crops improve soil structure and porosity, facilitating greater water infiltration and storage.
- **Raised and sunken bed systems:** The raised and sunken bed system is an effective land configuration technique for optimizing water use, particularly in high rainfall areas. Raised beds facilitate better drainage and aeration for upland crops like bhindi, chilli, capsicum etc. while sunken beds retain water, making them ideal for rice cultivation. These systems can improve water use efficiency by 30–50% compared to conventional flat planting. The higher cropping intensity and diversification promotes higher income to farmers.

***Enhancing water availability*:** Conserving the excess rainfall of kharif for growing rabi crops during rainless periods is crucial for optimizing water use. Rabi (winter) crops are crucial for enhancing cropping intensity, food security, and farmer livelihoods in these fragile hill ecosystems. Some of the promising technologies are discussed below:

- **Jalkund (Rainwater harvesting):** *Jalkund* is a small, low-cost, dug-out rainwater harvesting structure designed to collect and store runoff water, which is particularly important for growing winter crops in the NEH region of India. The *Jalkunds* can store 20,000–40,000 of rainwater, providing a reliable water source for irrigation in winter. Utilization of *Jalkund* water for cultivating winter crops like vegetables, mustard, and pulses can enhance yield up to 30–50% and improve cropping intensity. Moreover, *Jalkunds* supports integrated farming systems by supplying water for livestock and horticulture. This simple, cost-effective technology can significantly enhance water security and income generation for small and marginal farmers in the hill region.
- **Check dams and farm ponds:** Like the Jalkunds, the check dams and farm ponds also act as storage tanks, collecting the rainwater and surface runoff. A farm pond can store up to 5,00,000 L of water. These systems not only improve water availability but also support groundwater recharge, livestock watering, and climate-resilient agriculture for small and marginal farmers in the region.
- **Micro-irrigation techniques:** Besides moisture conservation and rainwater harvesting, achieving high water-use efficiency is essential during rainless winters in hilly conditions. Micro irrigation (drip and sprinklers) ensures very high water use efficiency (80–90%) by delivering moisture directly to crop roots, enhancing productivity, conserving water, and enabling off-season cultivation for small and marginal farmers. High-value crops like potatoes, tomatoes, strawberries, fruit crops, and vegetables (cabbage, cauliflower) can be grown

Jalkund at the ICAR-Research Complex for NEH region *(Source:* ICAR)

successfully with 40–60% less water than with conventional irrigations. Under hilly slopes, the gravity-fed drips can be sustainable alternatives, saving power and money. By adopting micro-irrigation in high-value crop production, farmers can enhance their profitability, optimize input use, and support sustainable winter farming in the undulating topographies of the regions.

Crop management strategies: Crop management trategies are very effective in allevating soil moisture stress under dry conditions beside *in situ* and *ex situ* moisture conservation techniques. These practices often used as a contingency crop planning under drought conditions. There are several crop management strategies discussed herein.

- **Drought-tolerant and short-duration crop varieties:** Crops that require comparatively lower water for growth, such as mustard, millets, beans, and legumes should be included for *rabi* cropping in north eastern India. With lower cumulative ET, short duration, drought tolerant varieties are always preferred for water scare regions.
- **Zero-till farming in rice fallows:** Zero-till farming in rice fallows during winter is an important strategy for improving land and water use efficiency in the north eastern region of India, where large areas remain uncultivated after the *kharif* rice harvest due to limited soil moisture and delayed land preparation. By eliminating the need for ploughing, zero-tillage allows for the timely sowing of winter crops like lentil, chickpea, mustard, and linseed, making better use of residual soil moisture. Zero-till farming can reduce turnaround time between crops by 7/10 days and save up to 30–40% water compared to conventional tillage.

Jalkund, An alternative potential rainwater harvesting structure in Wokha district, Nagaland- A case study

Jalkund water can be a substantial source for winter kitchen gardening. To explore this possibility, Singh *et al.* (2018) conducted five on-farm trials involving *Jalkund* technology across Wokha district of Nagaland in 2018. The *Jalkund* water was used to meet livestock rearing and fish stocking beside diversified crop water requirements. The rainwater harvested at different *Jalkunds* can meet up 240.5 m² crop cultivated area in Vegetable Village, 415 m² area in Niroyo village, 385 m² area in Wokha, 375 m² area in Longsachung and 700 m² in Longsachung (LNH) with an average annual water availability of approximately 55,986 liters. The economic returns from these *Jalkund* based systems were also very impressive. The *Jalkund* at Vegetable Village showed the highest B:C ratio of 2.53, followed by LNH (2.25), Niroyo village (2.17), Longsachung (2.00), and Wokha (1.73). The average net income generated from all five *Jalkunds* was estimated at around ₹ 17,340.00.

Table 1. Utilization of Jalkund water for diversified farm activities and its economic analysis in Wokha village

Activity	No. of Plants/ Livestock	Cropping area (m²)	Water requirements	Total water requirements (L)	Crop/ Livestock Production	Gross Return (₹)	Net Return (₹)	B:C ratio
Cabbage	520	150	600 L/irrigation	15429	520 kg	10400	5600	2.17
Fish Stocking	500	20	-	-	500 nos	7500	5500	3.75
Nursery raising	500	200	1000 L/irrigation	52000	5000 nos	30000	10000	1.50
Pig	2	15	120 L/day	43800	140kg	21000	8000	1.62
Total		385		111229		68900	29100	1.73

Source: Singh *et al.* 2018

SUMMARY

The hill ecosystem presents a unique opportunity for sustainable agricultural intensification, with abundant natural resources such as land, water, and groundwater. With scientific interventions such as micro-irrigation, rainwater harvesting *(Jalkunds)*, and *in situ* moisture conservation practices, the problem of moisture stress in winter can be effectively addressed. Traditional practices, such as bamboo drip irrigation and mixed cropping, also offer valuable insights into sustainable water management. However, greater awareness, capacity building, and access to resources are needed to scale these practices effectively. Strengthening research-extension linkages and promoting participatory technology development can ensure that farmers adopt appropriate and affordable solutions. Additionally, the integration of real-time weather forecasting and soil moisture monitoring can help optimize irrigation scheduling and input use. Policy support in the form of subsidies for water-saving technologies and promotion of agroecological practices is vital for broader adoption. Going forward, a multidisciplinary, community-driven approach is essential to build resilience against moisture stress and ensure sustainable agricultural growth in the fragile hill ecosystems of northeast India.

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