

Soil moisture conservation

in water-deficit hill agriculture: Affordable to small landholdings

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Rain-fed agriculture in the hills of north-eastern India is at the risk of crop failure, primarily due to over-dependence on inconsistent distribution and variable intensity of rainfall. Intermittent long dry spell between monsoon months (June–September) delay the timely planting of summer crops. In the rainless (<200 mm annually) months (November–March), moisture stress in sloping upland restricts rabi (winter) cultivation to <20% of kharif (rainy) area (4.24 million ha). Adopting soil water conservation practices (SWCPs) in situ or ex situ may benefit to address these constraints. The recommended SWCPs such as watershed engineering and mechanical measures are skill-oriented, expensive and difficult to implement and maintain on marginal/small hilly farms. This article proposes some of the simplest yet cost-effective and affordable SWCPs to mitigate moisture stress while expanding rabi agriculture and improving existing low cropping intensity (~120%) for food and nutritional security in the region.

Keywords: Hill agriculture, Rain water harvesting, Soil moisture conservation, Water deficit agriculture

UNTIL recent decades, agricultural drought was very rare in the highlands of north-east India. However, in the recent decades (1991–2020), the uncertainty of rainfall occurrence and spatial distribution has doubled, (coefficient of variation, CV: 27.8%) relative to the distant past (1901–1930). There has been a considerable increase in the incidence of agricultural drought like scenarios, even in monsoons (June–September). Occurrence of droughts in the early parts of the monsoon months forces the farmers to delay planting of rainy (*kharif*) crops and incur severe losses in crop yields. Delay in harvesting the *kharif* crops, delays the sowing of the resulting rain-fed winter (*rabi*) crops and is exposed to severe water stress during the dry months (November–March, <200 mm annually). Soil moisture content in sloping uplands during this period is less than the critical threshold (<15% weight/weight) to support cultivation of winter crops including vegetables.

The lack of structured irrigation facilities and rolling topography makes it difficult to access certain small but dispersed bodies of water and increases the risk of partial or complete crop failure. This compels farmers to rely on *kharif* monsoon crop, while during the *rabi* season, the same land stays fallow. As a result, cropping intensity (~120%) and crop-land utilization index (<40%) in these region remains one of the lowest in the country.

Lack of appropriate efforts to harvest monsoon rain, restrict its use in meeting upland crop water requirements during *rabi* season. Unfortunately, recommended soil water conservation practices (SWCPs) in the literature, such as watershed engineering and mechanical measures, involve huge initial investment, skills to implement and are difficult to self-sustain. Poor rural and socio-economic environments, with marginal land holdings of the region's farming population cause

extremely low-level of adoption of these costly and collaborative SWCPs.

Affordable *in situ* soil moisture conservation measures

In situ conservation of soil moisture is primarily about preserving rainwater in the soil matrix (recharge of the soil moisture profile) for a longer period by increasing infiltration, while reducing surface runoff, storm water and evaporation. This practice aims at retaining soil moisture in the root zone and making it available for *in situ* root uptake during the periods of water stress. The inexpensive technology of collecting rainwater and its use during the months of water shortage is becoming popular in the region.

Low-cost water harvesting structure

The region's upland receives an average annual rainfall of >2000 mm and almost 70% of it occurs during the monsoon. Constructing low-cost (₹17000–25000) water



Low-cost jalkhund of 30 m³ storage capacity

harvesting structures like, jalkhund of volume 30–90 m³ before the onset of monsoon can store nearly 30000–94000 litres of rainwater (free of sediments) from upper catchments. Its minimum shelf life is about 3 years and every year 450 m² of winter vegetables and other produce (10–13 quintals) of agri-products can be irrigated which could fetch a remuneration of ₹27,000 annually from a jalkhund of size 90 m³. Besides other basic indoor needs, off-season water needs of livestock, including the fish can generate nearly ₹20,000 annually.

Mulching

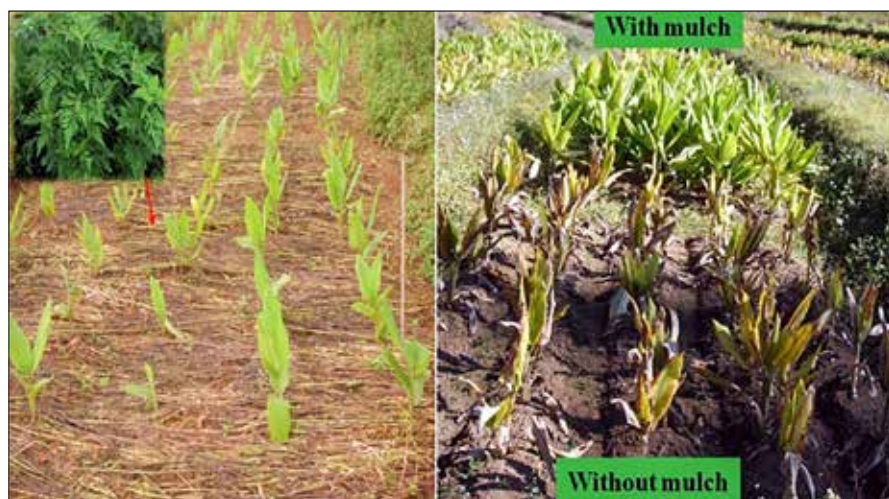
Mulching is an age-old practice in this high rainfall region, but the practice is not followed widely by the farmers of the region. Lack of knowledge and awareness of the benefits of mulching is a major reason for its low adoption.

Bio-mulching: Using biomass of weed/crop residues as mulch, alters *in situ* water balance component, specifically reducing the evaporation, while increasing the infiltration and percolation of rain water in the root zone (profile moisture recharge). It also helps in

reducing splash erosion, surface run-off and evaporation. During decomposition, the succulent biomass adds nutrients to the soil that improves soil aggregation and modifies the structural pore geometry to retain water for a longer duration. It also inhibits the weed growth and consequently reduces competition for water need. In farmers field (East Khasi Hills, Meghalaya), use of fresh mixed weed biomass as mulch in vegetables (e.g. cabbage, cauliflower, radish, carrot and kehl rabi), during 2019 increased the yield by 23.9–50.0% over non-mulched crops.

Long duration (April–January) spice crops like turmeric is grown rainfed in sloping highlands. Research results from the ICAR Research Complex for NEH revealed that, on application of succulent mixed weed biomass (@5.0 tonnes/ha, fresh weight basis), twice (pre-monsoon and monsoon month) in the life cycle of the crop, increases the yield of rhizome by 2 fold (17.0 tonnes/ha), relative to non-mulch crop. Similarly, crop water productivity (fresh rhizome yield per unit of rain water) increased by 95% over non-mulched crop. One of the reason is the improvement in the soil hydro-physical health (as profile moisture was 7–11% in the upper 45 cm depth during water-stressed periods), better soil aggregation (19–21% higher mean weight diameter), and 16–18% higher hydraulic conductivity in the top 30 cm soil depth.

Stone mulching: In steeply sloping eroded (vegetative coverless) highlands, a rocky surface devoid of real soils, filled with stones, gravel and rocks is exposed abundantly. In such degraded hills, afforestation through agroforestry or fruit/horticulture trees is a feasible option. The use of locally available crushed stones, rocks and gravel can be used as mulch to protect the soil from erosion. Stone mulching also modifies hydro-thermal regimes in the root zone, recharges soil profile moisture through increased infiltration and percolation, reduces weeds and preserves soil moisture. From a simulated study, it is



Bio-mulching in turmeric avoided pre-mature crop death

reported that stone mulch can be an effective adaptive strategy to reduce soil erosion up to 13.3 tonnes/ha on steep slopes (>32%), even in the increased intensity of precipitation in the projected climate change scenarios at Umiam, Meghalaya. They are also permanent in nature, economically viable in the long term, environmentally friendly and require less maintenance.



Stone mulching in degraded hills

Biochar application

Northeast India is rich in biodiversity and produces enormous phytomass, mainly attributed to the favourable climate (rainfall and temperature). In traditional agriculture, annually 10 tonnes/ha of vegetation biomass is burned and wasted. So instead of burning them in open aerobic condition, they can be converted into biochar, in a cost effective way of anaerobic pyrolysis in closed trenches, so that resource poor farmers can adopt forging un-affordable, expensive

and sophisticated biochar units. The conversion of fresh weed biomass into biochar has several benefits, namely (i) can raise carbon content from 40% in fresh biomass to 70–80% as biochar, (ii) increase the decay half-life by several hundred years ($t_{1/2}$ biochar: >80 years against few months in fresh biomasses) and can therefore provide a credible carbon sink and (iii) increase absorption area, soil structural improvement including changes in pore geometry and retention of soil moisture for a longer period of time.

Mini-bed and furrow planting system

Farmers in this region grow upland crops, sensitive to temporary water logging stress (e.g. maize, turmeric and ginger) in ridges like mini beds, leaving the furrows in between the ridges exposed to heavy rain and soil erosion along the slopes. Instead of keeping the furrows exposed, cover crops and sweet potatoes can be planted.



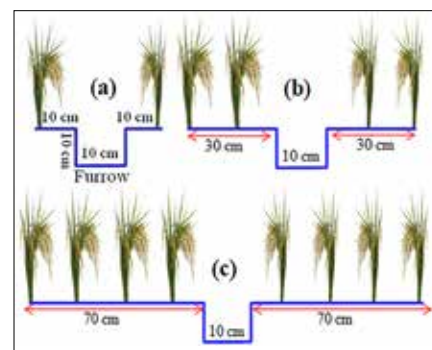
Demonstration of ginger in mini-bed and sweet potato in furrows

Reduce the free-flow of runoff water and sediment loss, while increasing the infiltration and profile moisture

It can also increase the cropping intensity and crop productivity from the additional crop grown in the furrows.

In situ furrows as inter-rill rainwater conservation

The opening of small-width furrows (up to 10 cm) at various row intervals increases the soil profile moisture recharge by capturing rainfall through prolonging infiltration in monsoon, while it decreases the free flowing runoff water along the steep slopes. In sloping (35%) uplands at ICAR Research Complex Regional Center (Basar), Arunachal Pradesh, *in situ* furrows at regular and alternate row intervals increases profile moisture recharge by 1.89–3.2 fold in the top 60 cm depth, rainfed upland rice productivity by 20–34% and water productivity by 23–33% as compared to flat planting.



Furrow at (a), continuous; (b), two ; and (c), four rows interval in upland rice cultivation

Soil pits

In this method, some deep holes of dimension 10–15 cm in diameter and 70–100 cm deep in a zigzag fashion are made either manually or by a dibbler in between rows of standing *kharif* season crops (monsoon months) in the sloping uplands. These holes are filled by placing crop residues (rice straw/maize stem) for rain water percolation in the soil profile (*in situ* moisture recharge). In the water-stressed months, capillary rise of the residual moisture recharged in the profile will help in the germination and early establishment of *rabi* crops.

Vegetation barriers

Upright, stiff-stemmed and dense perennial vegetation, mostly grasses



(a–c), raw materials; (d), biochar; (e), soil application; and (f), maize crop performance



Soil pit filled with maize stalk for soil moisture recharge

(e.g. Vetiver and Napier) with the profuse root system can be planted in narrow (30–90 cm wide) and parallel bands, along the border or near the bund. They reduce runoff and nutrient loss by encouraging the retention and infiltration. They control soil erosion and loss of fertile top soils, trap sediment and facilitate benching of sloping cropland.

prevented burning while reducing severe soil erosion. Additional measures like, conservation furrows (10 cm deep by 10 cm wide) after the interval of 2 rows with rice straw retention increased the moisture storage by 12–17% in the same field. Conservation furrows were also effective in retaining the eroded soil and thus contribute significantly to the accumulation of organic matter and other nutrients in the soil.

Seed hydro-priming: Seed hydro-priming (SP), by soaking the seeds (12–24 hours) in water before sowing, preferably with aerated distilled water improves germination, early emergence, development of roots and shoots, vigorous growth and seedling length, even in soil stressed by moisture. To avoid loss of plant population stand during early growth stages, low cost seed priming with running tap water or free flowing spring water is a feasible option for marginal resource poor farmers. Resiliency to stresses like drought and heat are some of the main benefits of seed hydro-priming in many field crops (e.g. millets, rice, maize, peas and pigeon pea). Experiments at ICAR Research Complex for NEH revealed that SP for 24 hours significantly ($P < 0.05$) improved the seed germination and crop stand, rice grain yield by 30–36%, water use efficiency by 29–36% and energy productivity by 15–22%.

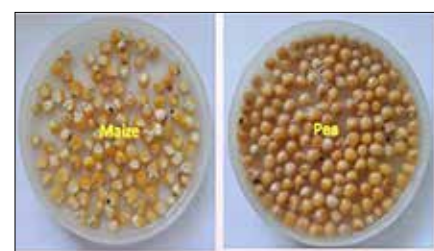


Vegetative barriers/grass buffer strips in cole crops

Soil moisture conservation measures specific to shifting cultivated hills

After harvesting jhum rice, residues including straw retention (15–20 cm tall) could significantly help to retain post-monsoon rainwater (~400 mm) *in situ*. From an experiment at ICAR Research Complex for Arunachal Pradesh center, paddy straw retention in jhum field increased the moisture content by 4–9% (weight basis) in the top 60 cm soil depth. Residue retention

From the same experiment, it has been reported that with rice straw retention and conservation furrows, an additional yield of 614.0 kg of Toria seed was recorded in the post-rice jhum field. In addition to crop intensification, these measures may help to prevent degradation of the traditional jhum field. This can help farmers avoid the common practice of abandoning the jhum land after 2–3 years of continuous cultivation.



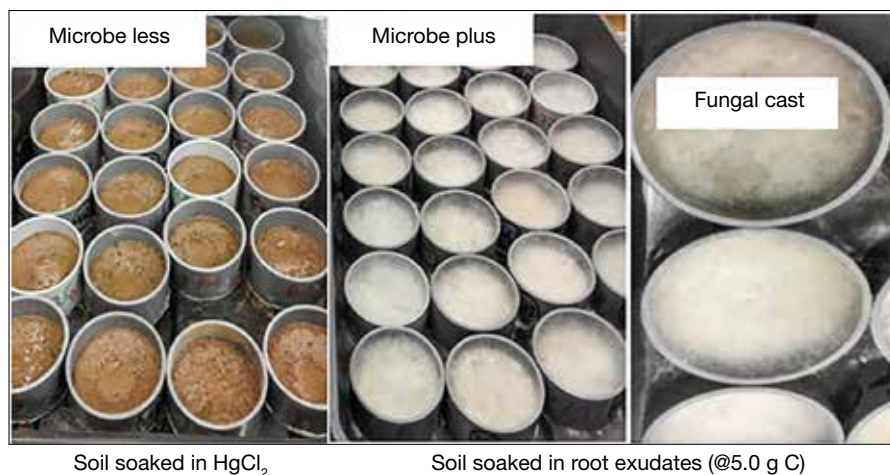
Seed hydro-priming in maize and pea



Traditional jhum field (left) and the improved jhum field with moisture conservation measures

Soil biological health

Any measures, such as adding organic matter through manure application or adding succulent weeds or selecting crops with higher root exudates contribute to the growth of soil microbial population. Microbes in water-stressed environment act as artificial storage of water by absorbing the water in their body and increasing



Addition of root exudates on microbial population and water availability

the effective surface of the pores in order to absorb more water. In the extreme water-deficient environment, microbes die and they release the water into the soil system which can supply water for another two weeks. From a collaborative experiment, ICAR Research Complex for NEH reported that root water uptake increased with the increase in microbial population,

while suppressing the unproductive evaporative losses of water.

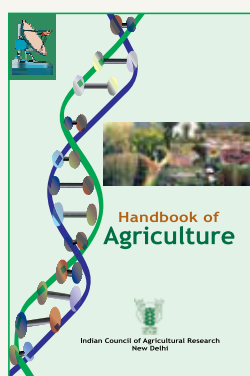
SUMMARY

Adopting these low-cost, less laborious and farmer-friendly soil and water conservation measures (SWCM) can increase the likelihood of immediate crop intensification, especially in rainfall-fed agriculture after the monsoon. This may improve

the existing low cropping intensity (120%) and cropland utilization index (<40%) in the region, while improving system productivity, livelihood and nutritional security in rain-fed hill agriculture of north-eastern India. As climate change may further increase the severity of soil erosion, especially in traditional mountain agriculture and more water-stress in post-monsoon rainless months. Therefore, adoption of these farmer-friendly SWC measures can serve as potential adaptation strategies to water-deficit agriculture for broadening *rabi* campaign, while minimizing the severity of soil erosion. By supporting capacity building and preventative adaptation measures, socio-economic resilience of ethnic tribal communities in different parts of the mountain states of northeast India can be further strengthened.

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