Conservation Agriculture for Carbon Sequestration and Sustaining Soil Health

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Conservation Agriculture for Sustainable Hill Farming

Sher Singh, S.C. Panday and J.K. Bisht

Introduction

The hills and mountains are one of the most important agro-ecosystems that supports life of half of the mankind either directly or indirectly. In India, hills are rich source of bio-diversity and possess enormous potential for sustaining agriculture, including horticulture and animal husbandry. The ecological fragility and vulnerability of the Himalayas to climatic aberrations, increasing demand for land to grow more food have been issues of concern for quite some time. Nearly 59% of the total work force in the Himalayas is engaged in subsistence agriculture which is barely enough to feed the growing population for 5-6 months in a year (Raizada *et al.*, 2009). The North-West Himalayas (NWH) consisting of Jammu & Kashmir, Himachal Pradesh and Uttarakhand spreads to 33 million ha, habited by 25 million humans and 19 million livestock. Though, the whole economy of the region is based on agriculture, the total cultivable land is only 3.2 million ha of the total geographical area of the region (Srivastva *et al.*, 2009).

The hilly region on account of its topography, peculiar geographical features and special problems (like higher runoff and soil loss, acidic soils, cultivation of steep slopes, more loss of nutrients and organic carbon on accounts of intense rain and runoff etc) forms a distinct socio-economic region as compared to plains and have certain advantages over the plains. They have a vast wealth of natural resources - natural vegetation, fertile soil, forests, pastures, lakes, and snow-clad mountain peaks. Hills are also the sources of perennial waters to the plains. All these resources must be properly utilized and harnessed for faster development of hills and hill people. NW Himalayas are capable of supporting the growth of a variety of crops because of varied agro-climatic conditions. Disregard to this eco-system, extreme variations in growing conditions, very small holdings, remoteness of villages, degraded watershed and poverty are serious challenges to sustainable hill agriculture.

The development of the hills is primarily linked to the development of agriculture and its allied activities. Agriculture is the main economic activity in the NWH region and despite the major impact of the green revolution in the irrigated areas of the country; modernization of agriculture has escaped this region as evidenced by the poor adoption of modern technologies, low consumption of fertilizers and other indicators of growth. One of the most important reasons for this slow growth is the lack of location-specific and system-based technologies.

Characteristic and Problems of Hill Farming

In NWH, traditional agriculture is largely a low input low production, subsistence system. The majority of hill farmers still follow the age-old practices which fail to realize the full potential of agriculture. Hill agriculture is also heavily dependent on forests for energy supply, fodder, water and non-timber products. The human and livestock population is larger, cultivation more widespread; fields are more fragmented and are on marginal lands, overgrazing persists along with over cutting of forests for fuel wood, fodder and timber. Ironically, the hill population is today no longer able to sustain itself at the level of self-sufficiency that was present over a hundred years ago. About 90 per cent of the total cultivated area in the NWH is rainfed. Accessibility is very poor and often necessary infrastructure is absent. The harsh climate and strong adverse growing conditions make farming very challenging (Srivastva, 2006).

Excessive/meagre rainfall, relatively low temperature, poor and shallow soils and soil erosion in terms of loss of fertile top soil are the major natural problems that plague the sustained agriculture in the hills. Low temperature and sunshine due to altitude and aspect severely limit the choice of crops and extent of growing periods. The spatial spread of hill agriculture, encroaching marginal lands, can severely damage to natural environment due to losses related to soil erosion, organic carbon, bio-resources and depletion of soil fertility.

The factors responsible for the loss of soil material are rainfall, land slope, slope length, vegetative cover density and management practices. The most harmful factor is the farming practice which is found in various forms prone to erosion. Every year more and more land is becoming denuded due to unplanned agricultural expansion. The impact of high intensity rainfall followed by run-off over greater slope length results in tremendous soil loss. The effect becomes more deleterious with the steepness of the areas. In some cases, the impact is so pronounced that the sub-surface bed-rock is exposed. Currently, soil erosion, poverty and water shortages are three major problems that affect the development of agriculture in this region. Climate variability and change pose a substantial risk to livelihoods and economic activities in the hills. Many households that are vulnerable to food insecurity are highly susceptible to weather shocks and climatic hazards too. The uplands are a difficult environment for farming and need to be carefully managed.

Agricultural practices resulting very high production supported by heavy external inputs may not be ecologically sustainable, whereas those which are ecologically sustainable may not be profitable. Thus a holistic approach giving due priority to sustainability, productivity and economic viability needs to be developed. Increase in population beyond a threshold level and mismanagement of resources accelerate the threat of degradation and stress to fragile hill ecosystem (Lal, 2001). Since agriculture, in major parts of the hills, is carried out at subsistence level, there exists enormous scope for improvement in the productivity simply through adoption of improved seeds and the recommended production technology. Given the complexity of problems in enhancing productivity of hill agriculture in the years to come, future gain will essentially come from gain in the productivity through the generation and adoption of appropriate agro-technologies.

Potential of Conservation Agriculture in Hills

The conventional or traditional mode of agriculture through intensive agricultural practices was successful in achieving goals of production, but simultaneously led to degradation of natural resources. The production cost has increased as a result of escalating prices of inputs and different field operations. The availability of agricultural labour has further reduced due to large scale migration of the people to the plains or big cities to earn livelihoods. In addition, the diverse challenges and constraints such as growing population, increasing food, feed and fodder needs, climate change, new parasites, slow growth in farm income and new global trade regulations demand a paradigm shift in agriculture.

The Hill Agriculture is facing a shift from subsistence agriculture to profitable crop production. In recent years, growing populations and deteriorating agricultural land have led to an increased need for improved agricultural technologies to increase soil and water conservation as well as crop yields. For improvement of agro-socio-economic conditions of the hill people, there is a need to develop scientifically improved technologies which are best suited to the agro-climatic condition of the hills. Intensification of hill agriculture without conservation involves high risk of degradation (Srivastva, 2006). Since, the diverse agro-climatic conditions of hills impart a unique advantage and competitive edge over a plain region, conservation agriculture (CA) in the hill farming systems has to be different compared to plains in managing the different production systems. Thus, in view of widespread resource degradation and to reduce production costs, increase profitability and make agriculture more competitive, CA can prove a vital tool in addressing these issues directly.

Conservation agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource-efficient and resource-effective agriculture. CA is gaining acceptance in many parts of the world as an alternative to both conventional agriculture and to organic agriculture. It is now experiencing a persistent and steady growth at global level and is now practiced in all the continents in more than 50 countries and all ecologies, including the semi-arid Mediterranean environments and the area is expanding rapidly (Kassam and Friedrich, 2009). In situations of resource-poor farmers in Africa, Asia and Latin America, CA systems are becoming increasingly relevant for addressing their needs and the challenges of resource degradation, sustainability, food insecurity, poverty alleviation, climate change, labour shortages and high energy costs. Not only it generates immediate benefits in terms of increased farm productivity, it also offers social benefits of great relevance to hilly region. In order to achieve the food security for millions of rural poor, it is critical to enhance the productivity of rainfed agriculture through conservation of natural resources such as water and land. Saving in man power or draught animal power is expected with the adoption of direct seeding conservation agriculture.

Unlike irrigated production systems in the plain regions where in CA practices were studied extensively in the context of the second crop in the season, there is need to assess the feasibility of CA systems in rainfed hilly areas which are mostly single cropped during the *kharif* season. It is observed that some regions with high rainfall show promise for CA adoption but needs the development of suitable practices. Conservation agriculture will be a "win-win" situation for both farmers and the environment. The successful introduction and later adoption of conservation agriculture practices depends on the way in which these practices are introduced, as well as their alignment with the community's existing belief systems regarding the agricultural practices.

Conservation Agriculture Practices for Hill Farming

Conservation Tillage

Conventional tillage leaves no land unploughed and leaves negligible residues in the field. In contrast, conservation tillage disturbs the soil to the minimum extent necessary and leaves at least 30 per cent residues on the soil. Zero tillage, minimum/reduced tillage and stubble mulch tillage are the components of conservation tillage. Conservation tillage can reduce soil loss by 50 per cent and conserves soil moisture to a great extent. Zero tillage involves planting seeds into soil that hasn't been tilled after the harvest of the previous crop. The crop germinates on residual soil moisture left by the previous crop, saving up to a million liters of water per hectare. Thus this technology provides greater opportunity for low cost of cultivation, higher net returns, better water productivity and improved soil health through better management practices for sustaining crop production in the hill eco-system (Panday *et al.*, 2008).

Conservation tillage, in addition to time and cost effectiveness, matches well with the fragile agro-ecosystems and poor socio-economic conditions of hill farmers (Table 1). Field experiments conducted at CSK Himachal Pradesh Agricultural University, Palampur (India) have established the beneficial effects of conservation tillage (mulch plus zero/minimum tillage) in hills under both rainfed and irrigated situations (Sharma *et al.*, 2009). Conservation tillage to wheat with retention of the material at the surface produced grain yield either equivalent to or greater than incorporation of this material at sowing in conventional tillage in hills of north-west India (Table 2).

TABLE 1: Sowing method-wise time requirement, energy consumption and cost of sowing for wheat and lentil crops at Almora

Tillage treatment	Man-hrs/ha Wheat	Bullock Energy pair-hrs/ha	Sowing cost consumption (MJ/ha)	(INR/ha)	Yield (q/ha)
		Wheat			
Conventional tillage	287.2	187.2	2073.6	6975	38.6
Conservation tillage	38.3	76.2	768.3	1916	39.1
		Lentil			
Conventional tillage	259.9	159.9	1799.8	6122	7.2
Conservation tillage	38.3	76.6	693.2	1916	8.5

Source: Subhash Chandra *et al.* (2006)

TABLE 2: Effect of tillage on grain yield of rainfed wheat at Palampur

Tillage	Grain yield (kg/ha)		
	1989-90[a]	1990-91[b]	1991-92[c]
T_1: Lantana application to preceding maize and its incorporation at sowing of wheat	3041	3892	2491
T_2: T_1 + conservation tillage in wheat	3242	4198	2737
T_3: Eupatorium application to preceding maize and its incorporation at sowing of wheat	2837	3761	2990
T_4: T_3 + conservation tillage in wheat	2992	4171	2438
T_5: Repeated tillage after maize harvest (farmers' practice)	1681	2251	1257
CD (P=0.05)	333	532	433

Source: Acharya *et al.* (1998)

[a]Sown on November 3; 5 rains of 69.5 mm in November and 4 rains of 114.2 mm in December.

[b]Sown on October 31; 3.4 mm rain in November and 7 rains of 261.8 mm in December.

[c]Sown on October 31: no rain in November but 24 mm rain 52 days after sowing and 3 more rains of 18.4 mm in December.

Reduced tillage can be successfully adopted in NWH without affecting productivity. It results in cost reduction, improved soil organic matter and water retention. Soybean-lentil and soybean-wheat are better options under reduced tillage (Singh *et al.*, 2008). Zero tillage saved time as well as resources without sacrificing yield. Conservation tillage improved soil organic C, plant available water capacity, aggregation and soil water transmission in the rice wheat cropping system. The adoption of zero tillage increased soil organic C content over conventional tillage by approximately 300 kg C/ha/year in the 0–30 cm soil depth in the sandy clay loam soil of the Indian Himalayas. Soil disruption though conventional tillage caused a reduction in soil organic C concentration and soil aggregation, especially in the surface soil layer (0–15 cm), indicating greater potential for soil erosion. The mean (of 4 years) yields and water use efficiency for both rice and wheat in the plots under zero tillage were not significantly different with those under conventional tillage (Table 3).

TABLE 3: Soil physical properties, soil organic C and yield at rice and wheat harvest (after 4 years of cultivation) as affected by tillage at Almora

Treatments	Bulk density (Mg/m^3)		Saturated hydraulic conductivity (cm/h)		Soil organic C(g/kg)		Plant available water capacity[a] (cm/15 cm soillayer)		Grain yield (t/ha)
	0-15[b]	15-30[b]	0-15[b]	15-30[b]	0-15[b]	15-30[b]	0-15[b]	15-30[b]	
			Rice						
Zero tillage	1.40	1.41	1.13	1.03	6.71	6.03	3.02	2.27	2.61
Conventional tillage	1.37	1.39	1.01	0.99	6.23	6.05	2.66	1.82	2.70
LSD (P=0.05)	0.02	NS	0.08	NS	0.28	NS	0.22	0.16	NS
			Wheat						
Zero tillage	1.36	1.38	1.37	1.18	6.78	6.09	2.72	2.33	3.40
Conventional tillage	1.34	1.36	1.27	1.22	6.35	6.12	2.07	1.74	3.63
LSD (P=0.05)	NS	NS	0.09	NS	0.30	NS	0.19	0.14	NS

Source: Bhattacharyya *et al.* (2008)

[a]Initial plant available water capacity data were 2.25 and 1.80 cm/15 cm soil layer for 0–15 and 15–30 cm soil depths, respectively.

[b]Soil depth (cm).

Selection of Crops/Varieties

There is ample scope in north-west hills to increase productivity as well as economic returns by selecting a profitable crop and high yielding varieties, which form the integral part of conservation agriculture. In harsh environment, the high yielding varieties of crops like pulses and oilseeds are beneficial due to their special characters like indeterminate growth habit, excessive foliage and flower production, and non-synchronous maturity, which suited the conditions of variable climate. The superior cultivars of amaranthus, buckwheat, horsegram, fingermillet and barnyard millet are more suited to marginal lands. On the other hand, the high yielding varieties of input responsive crops like rice, wheat and maize provide higher returns in favourable environment.

The rooting system, water requirement, absorption capacity and growth habit and canopy structures of different crops are quite different. Selection of a particular crop(s) depends on: nature of growing conditions, moisture, temperature, sunshine regime and terrains; domestic and market needs infrastructure; available input technology; traditional knowledge and experience of previous performance and limitations and policy decisions. The selection of crop(s) according to slope percentage is of great importance for hill farming. Selection of a crop having higher water use efficiency, profuse root growth and early seedling vigour can withstand moisture stress and provide good output in such areas.

Crop cultivars that make more efficient use of water and fertilizer N (including higher N fixation and N partition) while maintaining productivity and crop quality should be selected. Cultivation of N-efficient cultivars could help decrease fertilizer N inputs and resulting reactive N losses to air and ground water. These nitrogen-efficient cultivars could also be useful in regions where limited-resource farmers are unable to afford synthetic N fertilizers. Selection of N efficient varieties which can extract more N from soil at lower availability will enhance the production in these regions.

Sowing Method

Getting desirable level of plant population per unit area is a pre-requisite to obtain the potential yield of crop and it depends on the method of sowing. Broadcasting method of sowing is most popular in the hills. Though this method is quick and less energy demanding, but the crop suffers due to seed damages, uneven germination and poor plant growth. In contrast, line sowing not only improves the germination by putting the seeds in the moist zone, but also facilitates the intercultural operations. A yield advantage of 15-20 per cent has been recorded by line sowing over broadcast sowing (Subhash Chandra *et al.*, 2006). Under very poor residual soil moisture (3.3%) conditions in sandy soils, sowing of wheat with multi-crop planter resulted into highest emergence (37.7%) as compared to only 1.8 and 6.8% in broadcasting and manual line sowing, respectively. The sowing through multi-crop planter ensured placement of the seed in the moist zone with minimum load of dry soil on the seed.

Seed Priming

Soaking of seeds before sowing in water for a specific duration is known as seed priming. When soil moisture is not good enough to support the germination process, priming helps the seed to cope up with moisture stress. However, the response to the priming process depends upon the type of seed and moisture content of the soil. Several chemicals like PEG, KNO_3, KCl, which stimulate the germination process, have been found to improve the germination, but again their effectiveness depends on seed type and soil moisture content. In rainfed areas, overnight soaking of seeds results in early seedling emergence, better and more uniform germination, more vigorous plant, better drought tolerance, early flowering and harvesting, and higher yield. Even seed priming by H_2O (hydro-priming) with 18 hours; which is a simple, low cost and environmentally friendly technique; increased seed germination, seed yield and yield components in corn (Soleimanzadeh, 2013).

Remunerative Cropping Systems and Intercropping

The traditional cropping systems and mixed cropping, which have been evolved over the centuries and are considered as part of the subsistence farming to meet the increasing domestic food requirements, is an important practice in the hills of NWH. These have been determined largely by the climatic conditions particularly rainfall and temperature, natural resources, local food habits and socio-economic conditions. However, relative yield stability of these traditional systems without a temporal/spatial arrangement is at low levels with a high probability of crop failures.

In rain fed areas or in those having limited water availability, efficient crops should be identified, which can produce a significantly higher yield compared with the traditionally grown crops. As a thumb rule, crops having higher water requirement should not be included in the crop production systems, unless assured irrigation is available. In mid hills of Uttarakhand under rainfed conditions maize, soybean and June seeded rice based 1-year cropping sequences are more remunerative as compared to 2-years traditional cropping sequences (Table 4). Inclusion of legumes like soybean, lentil or pea in the sequence can further maximize the monetary returns and improve soil fertility. Thus economic viability of hill farming can be improved by the adoption of these cropping systems.

TABLE 4: Production and monetary returns under different rainfed cropping sequences

Cropping sequence	Grain yield (q/ha)		Net returns (Rs/ha/yr)
	Kharif	Rabi	
Traditional (2 yrs) with improved technologies			
Spring rice-wheat-finger millet-fallow	15.5, 26.8	28.1	1620
Barnyard millet-wheat-finger millet-fallow	16.0, 19.6	16.1	320
Spring rice-wheat-finger millet-toria	21.0, 25.1	24.1	1875
Improved (1 yr)			
Maize-wheat	51.9	23.4	4390
Maize-pea	51.9	11.1	4400
Finger millet-wheat	26.6	20.5	2300
Finger millet-pea	26.6	11.5	2900
Finger millet-lentil	26.6	12.0	3130
Finger millet-toria	26.6	7.20	1780
Barnyard millet-wheat	18.4	17.8	780
Barnyard millet-pea	18.4	15.0	2830
Barnyard millet-lentil	18.4	9.2	1280
Barnyard millet-toria	18.4	6.4	430
Soybean-wheat	18.9	22.8	4125
Soybean-pea	18.9	10.8	4150
Soybean-lentil	18.9	12.5	4800
Soybean-toria	18.9	7.8	3475
June sown rice-wheat	21.4	27.0	2660
June sown rice-pea	19.1	15.0	3086

Source: Ved Prakash *et al.* (1993)

Intercropping is one of the important ways to increase the productivity and provide income stability under limited soil moisture conditions. It acts as an insurance against hazards of weather, guards against crop failure by diseases and insect-pest incidence, ensures efficient utilization of land and other resources, thus, providing production stability. Promising intercropping systems in mid hills include fingermillet + soybean (1:1), paired row of maize (30/90 cm) +2 rows of soybean, maize for green cobs + black gram (1: 2), pigeon pea + finger millet (2:1), pigeon pea + soybean (2:2), finger millet (transplanted) + pigeon pea (4:1), okra + French bean (1:1), wheat lentil (2:1), wheat + mustard (2:1) (Ved Prakash and Narendra Kumar, 2006). In Himachal Pradesh, maize-radish-onion, maize-toria-potato, maize-toria+gobhi sarson and maize-gobhi sarson have been more remunerative over maize-wheat cropping system at farmers field (Chaudhary *et al.*, 2000). In sub-tropical conditions of Jammu and Kashmir, the promising cropping systems suitable for unirrigated, undulating/hilly areas with medium textured soils include maize+Rajmash-mustard, maize+Rajmash-wheat, maize+cowpea-gram, moong/mash/Rajmash-wheat (Sharma *et al.*, 1988). Intercropping of finger millet (transplanted) + pigeon pea in the row ratio of 4:1 proved better in terms of finger millet equivalent yield (66 q/ha), net returns (Rs. 20 thousand/ha) and LER (1.26) under rainfed condition (VPKAS, 2007).

Integrated Nutrient Management

Increasing input-use efficiency through adopting environment-friendly technologies like use of organic manures, crop rotation, integrated pest management, crop residues for organic carbon build-up etc. is the only way of lowering production costs. Soil is not an inexhaustible store of nutrients. For higher productivity, it needs higher inputs, and their productivity and efficiency also depends on their management. The high cost of fertilizers coupled with losses of fertilizer elements leading to environmental pollution and unsustainable crop production calls for substituting part of the inorganic fertilizers by locally available organic sources of nutrients viz. manures, green manures, crop residues, biofertilizers etc. in a synergistic manner, which is referred as integrated nutrient management. In addition to supply of nutrients, organic sources improve the physical condition and biological health of soil, which improve the availability of applied and native nutrients. However, due to paucity of organic sources of nutrients and their inability to meet total nutrient requirements to sustain large-scale inability to meet total nutrient requirements to sustain large-scale productivity goals to meet the demands of growing population, their integrated use with chemical fertilizers is inevitable. Soil productivity could be improved by application of 20:80:40 kg N:P:K + 10 t FYM/ha (to soybean only) in soybean – wheat sequence in the rainfed condition of NWH.

Mulching

Mulching acts as a barrier between soil surface and atmosphere thus prevents the loss of moisture and also moderates the soil temperatures. In regions of low rainfall, mulching helps in conserving moisture in the soil profile, and in high rainfall reduced runoff and soil loss which are reflected in an increase in crop yields. In hills one or the other organic material is available. Leaves of pine, oak, *Lantata*, crop residue, plastic sheets also serve as a good source of mulch. Pine mulch retained heat and resulted higher soil temperature by 2-4 °C (at 0-10 cm depth) in the morning whereas deflected radiation and resulted lower temperature by 3-5 °C at noon. This brought early emergence of potatoes by 4-6 days. The tuber yield increased by 35 per cent over control (Subhash Chandra *et al.*, 2002). Application of Lantana either as mulch or incorporation resulted into higher seedling emergence and grain yield and helped in the build-up of soil organic carbon (Sandal and Acharya, 1997).

Availability of optimum seed-zone moisture content at sowing time of summer (kharif) and winter (rabi) crops is a major constraint to crop establishment in rainfed areas. Multilocation studies have shown that application of waste organic biomass as mulch in the standing kharif crops (like maize, okra etc.) At the recede of monsoon (first fortnight of September) resulted in in-situ moisture conservation in the seed zone and its subsequent carry-over for the timely sowing of the succeeding wheat crop. The efficiency of conserved moisture was enhanced by sowing rainfed wheat with minimum tillage. Mulch increased the grain yield and water use efficiency of rainfed taramira under rainfed conditions of the Shivalik foothill region. Thus, under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield (Mittal *et al.*, 1997).

Application of pine needles as mulch @10 t/ha at the time of sowing of potato improved tuber yield and water use efficiency and resulted in the saving of one irrigation equivalent to 40 mm (Acharya and Kapur, 2001) Thus, under moisture stress conditions, when moisture can be carried over for a short time or can be conserved for a subsequent crop, mulching can be beneficial in realizing better crop yield. In the hills, mulching seedbeds of vegetable crops such as cauliflower, onion, chilli and brinjal is a common practice during winter to avoid frost killing, moisture evaporation and to provide warmth and protection to the tender seedlings.

Contour Farming

Up-and-down method of cultivation is a common practice in the hilly areas. This practice facilitates rainwater to gain velocity, resulting in more runoff which erodes soil. On the other hand, when cultural operations are carried out across the slope, the furrows made by these operations form natural ridges, which accumulate runoff water and thereby reduce soil erosion. The counter ridges so created form a multitude of mini barriers across the flow path of runoff and these vastly improve the detention storage of the area. This will in turn increase the opportunity time and hence the infiltration of rainwater into the soil profile. In addition, the quantity and velocity of runoff water are reduced tremendously. The furrows developed by counter tillage operation catch and hold the water, which is available to the crops, which reflected in the higher crops yields (Acharya *et al.*, 1988). Development of terraces and construction of retaining wall of stone or vegetative barriers can be widely used to minimize the risks of soil erosion.

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Alternate Land Use Systems

All the rainfed areas are not suitable for arable farming due to uneven topography and serious imbalances could also occur in a hill farming ecosystem by cultivating the crops in marginal lands. Extreme variations in growing conditions of hill agro-ecosystems need alternate land uses for appropriate exploitation of the potential, thus leading to conservation of the resource base and improvement in productivity. Inclusion of trees and shrubs in this can lead to sustainable and healthy balance in an ecosystem, besides meeting the human and livestock requirements. Further, where there is competition of crop residues for other purposes, agro-forestry and alley cropping are good options as CA practices in such situations. Since farming in NWH has been closely integrated with forestry, greater thrust on agro-forestry will increase the production of wood, fodder, other minor products and environmental protection. The possible agroforestry systems suitable for hills are based on crops, forest and horticulture and include agri-silviculture system, silvi-pastoral system, agri-silvi-pastoral system, agri-horti system, silvi-horti system, silvi-horti-pastoral system, etc.

Improved Silvi-horti system consisting of pangola (*Digitaria decumbense*) + quairal (*Bauhinea variegate*), *Kharik* (*Celtis tetrandra*), pangola + *bhimal* (Grewia optiva) and *Cenchrus ciliaris* + *kharik* are suitable of hilly terrain conditions. In agri-hori system, crop can be grown in an alley in an orchard at least for the first 4 to 5 years. The associated crops (cereal, legume, oilseed, medicinal or aromatic plants) come as a bonus to the farmer, besides keeping soil erosion and weeds under check. Cultivation of turmeric (*Curcuma longa*) and taro (*Colocasia esculanta*) in the inter fodder tree space, has been found to enhance the productivity and profitability of the system (Bisht *et al.*, 2004). Maize and soybean during kharif while wheat and pea during rabi can be grown successfully under pecannut (*Carya illinoinensis*) tree with enhanced organic matter content of the soil.

Several appropriate technologies including the introduction of improved grasses and legumes through suitable methods have been evolved for improvement of grassland and other forage production systems under specific situations like sloping sides, degraded land and field terraces and hybrid napier (Hy. *Pennisetum purpureum*) was found most suitable. Closure of grassland for a particular period, fertilization and adoption of suitable cutting management practices has also shown great potential of increasing fodder production (Bisht *et al.*, 1999). Planting of grasses like pangola (*Digitaria decumbense*) under pine and deodar trees produced highest yield. *Thysonalaena maxima* was another grass which performed equally well under deodar trees. Growing of trees + pasture, increased the system productivity, enhanced fodder availability and checked the soil erosion. Cultivation of ginger and turmeric can be successfully done even under 10 years old fodder trees (*bhimal*, oak, *quairal*, *kharik*) (Bisht *et al.,* 2000).

Protected Cultivation of Vegetables at High Altitudes

Hills also have a comparative advantage over the plains for production of off-season vegetables, vegetable seeds, temperate and tropical fruits, medicinal plants and other high value crops. In Himachal Pradesh and Uttarakhand, the unique 'ecological niche' of the region, and better marketing facilities provided opportunities for 'off-season' vegetable cultivation of crops like peas, cucumber, cauliflower, brinjal, ginger, tomatoes, beans, radish, carrots etc. (Raizada *et al.*, 2009). Cultivation of off-season vegetables is more remunerative because vegetables in the hills are harvested at a time when these are not available in the traditional plain area.

Protected cultivation practices can be defined as a cropping technique wherein the microclimate surrounding the plant body is controlled fully as per the requirement of the plant species grown during their period of growth. Green house is a simple house covered with transparent film or glass though which sun rays enter inside and help in plant growth. As a result the solar energy remains trapped in the green house, thus raising its temperature. This condition of natural rise in green house air temperature is utilized in the cold regions to grow crops successfully. However, in summer season due to the above stated phenomenon, ventilation is required to maintain the temperature inside the structure well below 30-35 °C (Singh and Sirohi, 2006). The temperate regions of high altitudes remain under snow or low temperature from November to March and therefore potato, cole crops and root crops can be cultivated in open during summer. In rest of months vegetables can be cultivated in protected cultivation only. Crops like spinach (*palak*), fenugreek, coriander, vegetable mustard (*Lai*), radish and knoll-khol can be successfully grown in polyhouses during winter. Good yield of tomato, cucumber, capsicum, brinjal and chilli can be taken in greenhouses during summer months. Performance of some vegetable crops under protected and open field conditions at high altitude is shown in Table 5.

TABLE 5: Performance of important vegetable crops in polyhouses vs open field conditions at high altitude (300 m above msl)

Crops	Varieties	Yield (kg/m^2)		Per cent increase under protected condition
		Protected	Open field	
Tomato	Pusa Early Dwarf	3.017	1.089	177.04
Capsicum	California Wonder	1.946	0.897	116.95
Brinjal	ARU-1	5.152	2.650	94.40
Chilli	Pusa Jwala	0.468	0.286	63.64
Pea	Arkel	0.927	0.572	60.66
Bean	Contender	2.510	0.797	314.57
Palak	Jobner Green	1.015	0.626	84.35
Lai	ARU Black	1.366	0.656	108.23
Methi	Kasuri	0.844	0.593	42.37
Coriander	Bulgarian	1.738	0.369	100.00
Cucumber	Green Long	7.746	3.150	145.90
Squash	Australian Green	10.500	7.500	40.00

Source: Narendra Kumar *et al.* (2006)

Rainwater Harvesting and Recycling

In hilly regions, the runoff collected in the natural depressions can be recycled for irrigation to crop during the scarcity periods. But this type of water harvesting has to be followed on a community basis which has many limitations associated with it. The low discharge springs and streams in the hills usually have a discharge rate of 1 to 10 liter per minute. These are either unutilized or underutilized because of the higher proportion of application loses due to low discharge. Thus, water from such sources as well as runoff from impermeable surface of farmstead such as roof tops can be stored in tanks such as LDPE (low density polyethelene) film lined tanks at a lower cost for recycling. This can ensure vegetable production on fields located on a nearby farmstead round the year. Application of supplementary irrigation from the harvested rainwater resulted in significant increased in grain yield of soybean and wheat in comparison to rainfed conditions in light soils of mid hills of NWH (Table 6). Increase in water expense efficiency was also observed due to supplementary irrigation in both the crops.

TABLE 6: Effect of supplementary irrigation on grain yield and water expense efficiency of soybean and wheat

Treatment	Grain yield (kg/ha)		Water expense efficiency (kg/ha/mm)	
	Soybean	Wheat	Soybean	Wheat
Rainfed	1760	2310	2.0	10.9
Supplementary irrigation*	2010	3480	2.3	11.3
CD (P=0.05)	214	307	-	-

Source: VPKAS (2011-12)
**includes 100 mm water at critical stages*

The availability of water has improved the livelihood of the people in the Shivalik foothills of India (Figure 1). The fodder availability led to dairy farming following increased milk production and stall feeding of animals. The dairy farming is mostly managed by the women and the cash received through the sale of milk improved the women empowerment leading to increased attendance of female children in school, income generating activities and better childcare. The availability of cash increased the use of inputs in crop production leading to improved productivity. The stall feeding reduced the load on the community forest area for grazing and increased the availability of manures for crops. The introduction of agro-forestry proved a source of extra income for the farmers. The pruning material obtained from agro-forestry, especially during winter when fuel wood demand is at peak, fulfilled the requirement of fuel wood and reduced the load on the community forest area thus protecting the environment and saving time of women being consumed in its collection.

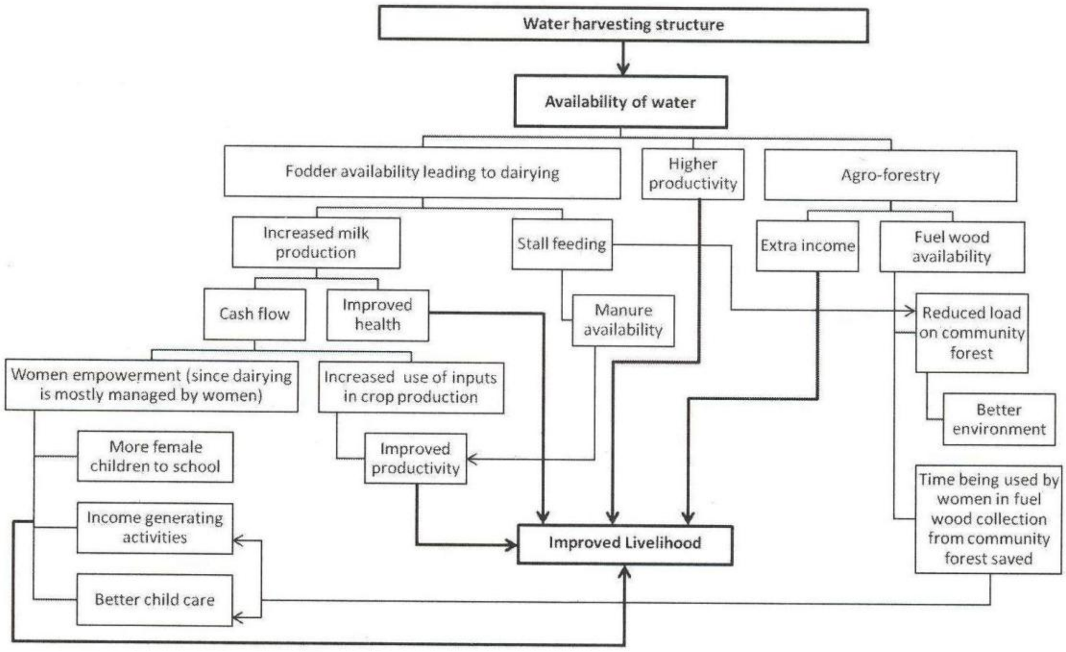

FIG. 1: Flow chart showing impact of water availability on the livelihood of farmers

Soil Conservation Measures

Soil erosion causes rapid fertility depletion, damages crops by sedimentation and raising stream beds/river channels by siltation which causes flash floods and limits discharge capacity, irrigation and navigation. So, soil conservation measures should always be a major consideration for sustainable hill farming. The common practices in the hill Tracts is to plant crops up and down the slopes which facilitate soil erosion with the onset of heavy rains. However, plantation should be made along the contours. Simple conservation measures like mulching can reduce topsoil removal. Crops like maize, sesame, turmeric and ginger gave a good yield of 3-4, 1-1.5, 20-30 t/ha respectively when cultivated with mulching. Studies showed that is zero-tillage with surface mulch reduced soil erosion by 3-6 times as compared to traditional method without mulch at 5-15% hill slope (Table 7).

TABLE 7: Effect of tillage and mulching on soil erosion in hill slope (5-15%)

Treatments	Dry weight of eroded soil (t/ha)
Mulch	22.25 b
No Mulch	58.02 a
Zero-tillage (dibble)	23.77 c
Minimum tillage (furrow planting)	35.68 b
Conventionaltillage (Spading)	61.13 a
Zero-tillage + Mulch	13.12 e
Zero-tillage + no Mulch	34.43 c
Minimum tillage + Mulch	20.12 d
Minimum tillage + no Mulch	51.24 b
Conventional tillage + Mulch	33.43 c
Conventional tillage + no Mulch	88.85 a

Source: Miah and Saheed (2013)

Integrated Farming System Approach

The hill farming agriculture requires an appropriate integrated farming system or holistic Approach, which would permit continuous sustainable production and the same time well adapted to the requirements of farming community. Within an agro-ecological zone, several farming systems are found in the hills with variation in resource endowment, preferences, and socio-economic position of the specific family. In natural resource conservation different topo-sequential cropping involving Agrihorti- silvi- pastoral system was found to be most economical with effective soil and water conservation measures. It is also possible to integrate different components of ecosystem (land, water, plant species etc) to obtain sustained production from waste, rainfed and degraded lands to check natural hazards like floods, drought and soil erosion. Special attention is required in selecting a proper site according to the slope, plant species and management of agrihorti-silvipastoral system in respect of land capability, water harvesting and cultural practices. Sound soil conservation and soil management practices should be an integral part of such farming system, to suit the specific location conditions of the varying elevations of the hills. The integration of farming system components of food crop, fodder, fruits and multipurpose trees are specific to the terrain conditions and production potential (Srivastva *et al.*, 2009).

Livestock production can be fully integrated within conservation agriculture by making use of the recycling of nutrients. This reduces the environmental problems caused by concentrated intensive livestock production. Integration of livestock into CA enables the farmer to introduce forage crops into the crop rotation, thus widening it and reducing pest problems. Forage crops can often be used as dual-purpose crops, for fodder and soil cover. However, in arid areas with low production of biomass, the conflict between the use of organic matter to feed the animals or to cover the soil still remains to be resolved.

Diversification of cropping systems based on the land capab0ility classes can lead to stability in crop production and income of hill farmers. Therefore, such cropping systems need to be pursued corresponding to variable climatic and edaphic environments. A matrix of possible land uses as influenced by resource carrying capacity (land capability class and mean annual rainfall) is depicted in figure 2. More profitable land use systems involving oilseeds and legumes (pulses) will become increasingly

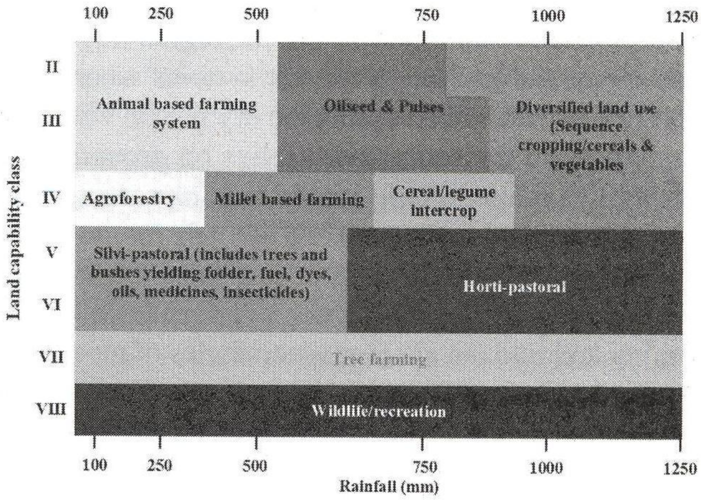

FIG. 2: Matrix of possible land uses as influenced by land capability classes and mean annual rainfall (*Source*: VPKAS, 2007)

important. Thus, hill agriculture can be made profitable by incorporating animals in the system; however, hills face chronic shortage of fodder especially during winter months which have to be given high priority in the cropping system.

Constrains in Adoption of Conservation Agriculture in Hills

Despite its advantages, for a number of reasons CA has so far spread relatively slowly. There is greater pressure to adopt CA in tropical than in temperate climates. The adoption of CA will probably depend on a mixture of public pressure to fight erosion and the financial incentives of reduced tillage. Farmers still do not feel sufficient pressure and environmental indicators (erosion, flooding) are not yet taken seriously enough. CA has great potential in NWH owing to its ability to control erosion, give more stable yields and reduce labour. There are a number of ongoing initiatives promoting different practices, from conservation tillage up to conservation agriculture. However, there are still some significant problems.

In contrast to the homogenous growing environment of the IGP, the production systems in rainfed and hill regions are quite heterogeneous in term of land and water management and cropping systems. In NWH conventional agriculture is in great difficulties because of environmental problems and because of a lack of sutiable farm machinery, which has to be replaced. Unless CA is adopted, the investment in new machinery will have to be very high. Converting to CA needs higher management skills. The initial years might be very difficult for the farmers, therefore they might need moral support – from other farmers or from extension services –and perhaps even financial support to invest in new conservation agriculture machineries/tools. The necessary technologies are often unavailable which might not be locally available. Few farmers take the risk of buying new machinery without knowing the system or even having seen it. Machinery dealers might not wish to promote CA as long as it is not supported by extension, since the widespread adoption of CA will reduce machinery sales.

Most of small holding farmers in the region rely on rice, maize, millets and wheat as their food crops and manage livestock systems where residues of these crops provide a vital source of livestock feed during the dry season when grazing areas are limited. Conservation agriculture on the other hand, relies on ground cover with crop residues to achieve its potential to increase crop yields and improve soil health and system sustainability. The competition between the soil and animals for the scarce crop residues thus is a major issue. Conservation tillage alone without residue retention may not be of much utility. Therefore, the real challenge lies in the ways and means of sparing the crop residue for conservation farming and find out alternative strategies of meeting fodder requirements of livestock. CA practice has to be adopted holistically so that it minimizes soil loss, conserves water and controls weeds which are essential for success of crop production under rainfed conditions.

Future Thrust

- Researchers and extension agents promoting 'best practices', such as conservation agricultural methods, without consideration of the local context may exacerbate the issue of sustainability of these practices. Therefore, development of conservation agricultural practices in the context of local agro ecological situations is necessary.
- Understanding the farmers' perceptions of their views of new conservation agriculture practices and their impacts on productivity must be considered before their introduction. Participatory approaches which involve those most at risk to climate change in raising awareness and implementing adaptation initiatives need to be adopted for this.
- CA represents a fundamental change in the soil crop-landscape system management and in the cropping system design and management which in turn will lead to consequential changes in the required operations and mechanization solutions. Therefore, development of innovative manual, bullock drawn and modular power tiller operated conservation agriculture farm machinery can make a significant impact on small and marginal farmers of hill agriculture where mechanization is very difficult.
- Since conservation agriculture implies a radical change from traditional agriculture, policy analysis should be in such a way that it can be understood how conservation technologies integrate with other technologies that promote conservation agriculture.

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