International Journal of Ecology and Environmental Sciences 47: 355-368, 2021
ISSN: 2320-5199 (Online)

Conservation and Sustainable Management of Traditional Agro-ecosystems in Central Himalaya, India

ABHISHEK CHANDRA[1*], VIKRAM SINGH NEGI[2], LAXMAN SINGH KANDARI[3], J. DINAKARAN[4], R.K MAIKHURI[5] AND KOTTAPALLI SREENIVASA RAO[6]

[1]*Department of Environmental Sciences, Sri Venkateswara College, University of Delhi, New Delhi,110021*
[2]*G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, 263 643, Uttarakhand*
[3]*Department of Forestry and Natural Resources, HNB Garhwal University, Srinagar Garhwal, 246174*
[4]*Department of Botany, Bhaskaracharya College of Applied Sciences, University of Delhi, Delhi, 110075*
[5]*Department of Environmental Sciences, HNB Garhwal University, Srinagar Garhwal, 246174 Uttarakhand*
[6]*Department of Botany, University of Delhi, New Delhi-110007, India*
E-mail: ac.india@gmail.com, ac@svc.ac.in (AC); vikramsnegii@gmail.com (VSN); luxkandari@gmail.com (LSK); jesudina@gmail.com (JD); rkmaikhuri89@gmail.com (RKM); rao.srkottapalli@gmail.com (KSR)
*Author for correspondence

ABSTRACT

Majority of population in the Indian Himalayan region resides in rural areas and depends primarily on farming system for their sustenance and well-being. This region has a long heritage of the subsistence economy, with agriculture being the core component involving over 70% of its population. Biophysical, socio-cultural and economic variations in the Himalaya have led to the evolution of diverse and unique farming systems, crop species/varieties and management practices particularly in the central Himalaya. Various types of traditional farming practices have been developed by the local community to conserve the crop diversity in the region. The local farming communities are the custodians for the improvement of crop diversity in the Himalayan region. Nevertheless, there is a steady decline in the cultivation of traditional crops, due to the perturbation of socioeconomic and environmental condition in the Himalayan region even though, several crop varieties are conserved because of their medicinal and religious values. In the region traditional crops were mostly replaced with cash crops during the recent past, due to the changing economic aspiration and as an adaptation to climatic variability. Therefore, the suitable policy and government support is warranted to conserve the traditional crop diversity, an advanced adaptation measures like making available information and sustaining sponsoring soil conservation practices, launching climate smart varieties and advanced adaptation measures based on various agro-ecological zones in the Indian Himalayan region.

Keywords: Biomass Production; Energy and Monetary Budgeting; Soil and Land Quality Indicators; Crop Rotation; Threats and Erosion of Agrodiversity; Socio-Economic and Religious Perspective

INTRODUCTION

The Himalayan Mountain is one of the most fragile and complex ecosystems, which provide home to 150 million people and spread over eight Asian countries i.e. Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan (Saxena et al. 2005). A difficult topography, high degree of inaccessibility, poor infrastructural facilities, and limited opportunities of income are responsible for poor economic conditions of the majority of local inhabitants. The region has a long heritage of the subsistence economy with agriculture being the core component involving over 70% of its population. Agricultural activities provide livelihood support to a large section of peoples' living in the Himalayan region (Maikhuri et al. 1996, 1997, 2001, Negi et al. 2012, Kandari et al. 2012, Negi and Maikhuri 2013). The traditional central Himalayan village is closely dependent on surrounding forest for utilization of resources, therefore more sustainable in ecological point of view (Chandra 2007, Nautiyal and Kaechele 2007, Chandra et al. 2011a,b). The conservation of traditional agrobiodiversity and their management is essential for sustainability of the landscape with mountains as it also influences the landscape in the plains and foothills of the Himalaya.

Worldwide for management of the natural resources suitable areas are converted into protected areas for achieving the goal of *in-situ* conservation of biodiversity. These protected areas, i.e., sanctuary, national park and biosphere reserve are also increasing interest of conservation and management of traditional crop diversity in natural conditions (Nautiyal et al. 2003). The subsistence farming systems have been adopted by the local farming communities in the Himalayan region due to climatic conditions, family size, location of farms and unavailability of market place (Negi et al. 2012, Negi and Maikhuri 2013). Most of the government agency experts have tried to apply the plains land policy and/ or philosophies for improving the subsistence farming systems practiced in the central Himalayan region (Maikhuri et al. 2011). The traditional conservation practices i.e., various indigenous methods have maintained several crop varieties and soil fertility in the Himalayan region. These socio-religious constraints are an integral part of their culture and also possess great ethno-botanical knowledge of traditional crops. They are still using many rules and regulations set up by earlier generations for the conservation and management of the agrodiversity to fulfil their requirement (Anthwal et al. 2006, Maikhuri et al. 1996, Chandra 2007, Chandra et al. 2011a, b, Negi and Maikhuri 2013).

The central Himalaya is well known for above 34 food crop species and numerous farmers selected land races and different types of cereals, pseudo cereals, millets, pulses, oilseeds, condiments, and vegetables (Maikhuri et al. 1997, 2001, Chandra et al. 2013). However, during recent past a decline in interest of local farming communities towards traditional crop cultivation has been observed as a result of climatic, cultural, and socioeconomic transformation (Chandra et al. 2013). The increase in acreage of agricultural land and reduction in forest cover is a common trend in the Himalayan region (Sen et al. 2002, Semwal et al. 2004) and other mountainous regions in developing countries (Palni et al. 1998). The overall trend is the loss of traditional crops and is replacing a wide variety of nutraceutical rich local crops and greater dependence on cash crops, with their expensive inputs. The expansion of potato, the by-products of which do not have any fodder value, implies a lower production of fodder from private farms and thereby greater pressure on forest use. Further, soil erosion from potato fields has increased up to 6-8 times higher than that from traditional staple food crops. Input of organic manure is also 2-4 times higher in cash crops. The consequences are disastrous because of genetic loss and decline in intensity and net area under cultivation and production of crops in central Himalaya (Maikhuri et al. 1996, 1997, 2001, Negi et al. 2009, 2012). Climate is greatly affecting the sustenance, resistance and quality of traditional crops in the central Himalayan region (Saxena et al. 2005). In some areas, the traditional farming practices are under threat due to change in weather patterns (Maikhuri et al. 1997, Nautiyal et al. 2002). The changes in agro-biodiversity are such that soil loss and runoff from the croplands have dramatically increased together with increases in local pressure on forests. In this review, we made an attempt to describe the significance of socio-ecological and religious perspective of conservation and sustainable management of traditional agro-ecosystems in central Himalaya, India.

Agroecosystems in the Himalayan region

Agro-ecosystems in the Himalayan region are complex and constitute forests interlinked production systems (Maikhuri et al. 1997, Rao et al. 2005, Saxena et al. 2005). Inaccessibility, environmental heterogeneity and ecological fragility favoured the evolution of subsistence production systems sustained with organic matter and nutrients derived from the forests (Rao et al. 2005, Negi et al. 2018). The agriculture is the mainstay of the people living in the Himalayan region because their activity on agriculture is land use directly influences the forest ecosystem services and other resources (Nautiyal et al. 1998, Saxena et al. 2005, Negi and Maikhuri 2012). Traditionally, agricultural land in the region is identified either as the rainfed (locally known as Ukhar) or the irrigated (known as sera). About 85% agricultural lands are rainfed and remaining 15% land falls in the irrigated category (Semwal et al. 2004).

In Irrigated cropping systems, there are two crops in every year, but in rainfed area cultivation of three crops and one fallow period in two years. The choice of fallowing and crops with management practices depends entirely on local farming communities (Maikhuri et al. 2001, Semwal et al. 2004, Chandra 2007, Chandra et al. 2011a, b, Negi et al. 2012, 2018). Inter-linkages between forestry, livestock and crop production characterize the traditional hill farming systems. The major source of nutrients for crops comes from livestock through farmyard manure (FYM) and compost (Dhyani et al. 2011). Typically, the animals are kept in stalls close to the house and fed with fodder, most of which (52%), comes from the forests (LRMP 1996). Exploitation of forest litter for bedding, composting and the tethering of animals on the fields are other pathways for nutrient transfer to crops (Sherchand et al. 1999, Chandra 2007, Chandra et al. 2011a). Recent changes in farming practices as a consequence of the increased population, deforestation, intensification of cropping and decreased labor availability have induced decline in livestock numbers per household with a concomitant reduction in rates of FYM/compost application (Turton et al. 1995, Chandra et al. 2011, Negi et al. 2012). In the traditional agro-ecosystems crops, livestock and forest are integrated in a way to maximize soil fertility and nutrient flow and better production (Mohamad Saleem 1998, Scoones and Toulmin 1998, Saxena et al. 2005, Rao et al. 2005). At this level, the spatial relationship between land uses may be influenced by nutrient flows and erosion dynamics resulting in redistribution of nutrients within the landscape, which is often central to the functioning of the agroecosystem. Powell et al. (1996) carried out such a landscape level study, integrating and analyzing the structural and functional linkages between croplands and rangelands and found that although rangeland nutrient balances were in equilibrium, croplands lacked the internal capacity to replenish nutrients lost as grain and crop residue off takes. Pilbeam et al. (2000) demonstrated the critical role of forested areas in the maintenance of equilibrium through net transfer of nutrients from non-agricultural to agricultural areas in Nepal thus endorsing the utility of landscape level studies. The extension of agriculture land in the natural forests combined with replacement of traditional crops with cash crops and multipurpose agroforestry trees in the Himalayan region are major problems for sustainable productivity of traditional crops (Singh et al. 1997, Saxena et al. 2005). The building of roads and access to markets has allowed a steady increase in fertilizer use in central Himalayas. Intensive use of fertilizers, manure and heavy machinery in conventional, arable farming systems can cause serious losses of nutrients and deterioration of soil structure. Agriculture may not be sustainable in the long run if high nutrient deficiencies occur at the expense of decreasing level of soil organic matter (Van Faasson and Lebbink 1994). Several traditional crops such as *Pisum arvense, Panicum milliaceum, Fagopyrum esculentum, Setaria italica, Fagopyrum tataricum,* have been almost extinct. Farmers have gained substantial economic benefits from cash crops. Indigenous innovations enabling improvement in the farm economy by conserving and/enhancing agro-biodiversity do exist, but are highly localized. The changes in agro-biodiversity are such that soil loss and run-off from the croplands have dramatically increased together with increases in local pressure on forests.

Major threats to agrodiversity

The sustainable development of Himalayan agro ecosystems depends on land use and management practices viz., using of bullocks for drought power, human energy as labour, crop residues as animal feed and animal waste mixed with forest litter as organic inputs (Chandra, 2007, Chandra et al. 2011a, b, Negi et al. 2018). The unsustainable land-use development in mountain accelerates soil erosion, which partly contributes to devastating floods in the plains, is the basic process for change in Himalayan landscape (Ives and Messerli 1989, Saxena et al. 2001, 2005). Earlier studies (Maikhuri et al. 1996, 1997, 2001, Nautiyal et al. 2002-2003, Chandra et al. 2010, Negi and Maikhuri 2013) reported about 34 crop species which includes cereals, pseudo-cereals, millets, pulses, oil yielding crops, and different types of vegetables are grown in the traditional agroecosystems. The common traditional crops grown in the region are *Oryza sativa*, *Triticum aestivum*, *Hordeum vulgare*, *Eleusine coracana*, *Echinochloa frumentacea*, *Setaria italica*, *Panicum milliaceum*, *Amaranthus* spp., *Fagopyrum esculentum*, *F. tataricum*, *Phaseolus vulgaris*, *Vigna mungo*, *Macrotyloma uniflorum*, *Glycine max* (local black seeded varieties), *Brassica campestris*, *Perilla frutescens*, *Sesamum indicum*, many local vegetables (cucurbits, *Trigonella* spp., *Beta* spp.) etc. The other crops viz., *Pisum sativum*, *Solanum tuberosum*, *Zea mays* etc. are also grown. Maximum area is covered by *O. sativa*, followed by *T. aestivum*, *S. tuberosum* and least by *S. indicum*. (Chandra et al. 2010). Several studies have reported the decline (72-95%) in diversity of traditional crops in the Himalayan region within a short period of time (Maikhuri et al. 1996, 1997, 2001, Negi and Maikhuri 2013). Nautiyal and Kaechele (2007) reported that the farmers of the valley were cultivating 65 landraces of different crops. The 57 and 39 landraces remained under cultivation after year 1980 and 1990 respectively in the valley. These crops have been mostly replaced by cash crops (Negi and Maikhuri 2013) such as *M. uniflorum* and *V. mungo* have been replaced by *Glycine max* and *Amaranthus* spp. due to changes in food habits of traditional societies. Initially food habits are providing energy, the latter does not provide enough protein and micronutrients and now population are leading to diseases and general lowering of the health (Shiva and Vanaja 1993, SFIW 2004).

The cultivated area of many landraces has been reduced to 80-85% and replaced by high yielding varieties (HYVs)/modern variety or introduced crop (Maikhuri et al. 1996, 1997, 2001. Negi et al. 2009, Chandra et al. 2010). Maximum decline in cultivated area has been reported for paddy landraces. HYV and landraces introduced in the village from the neighboring areas is increasing for getting more output in the form of grain yield has one of preference of farmer (Table 1). Green revolution made a signification contribution to decrease the problem of hunger due to HYVs, to produce and increase demand for food world over. Used of HYVs has many negative impacts on the unique Himalayan agro-ecosystems which depend on the resource and developed technologies by local farmers. Long-term consequences and creates nutrient imbalances, soil and water erosion done by agricultural intensification in these ecosystems (Maikhuri et al. 1997, Sen et al. 1997). Due to the tremendous variation in altitude, temperature, rainfall, soil type and ecological setting, as well as the diverse sociocultural condition and different levels of market integration of HYVs are

Table 1. Replacement of some traditional crop varieties by high Yielding/ introduced varieties in the Central Himalaya, India

Traditional crop	**English name**	**Replacement crop**
Avena sativa Linnaeus.	Oat	*Solanum tuberosum*
Echinochloa frumentacea (Roxburgh) Link.	Barnyard millet	*Cajanus cajan*
Eleusine coracana (L.) Gaertn	Finger Millet	*Glycine max* and *Amaranthus* spp.
Fagopyrum esculentum Monch	Buckwheat	*Phaseolus vulgaris*
Fagopyrum tataricum	Buckwheat	*Solanum tuberosum* and *Phaseolus vulgaris*
Glycine soja (Linnaeus) Merrill	Soybean	*Glycine max*
Hordeum himalayens	Barley	*Solanum tuberosum* and *Phaseolus vulgaris*
Hordeum vulgare L.	Barley	Improved varieties of *Brassica*
Macrotyloma uniflorum (Lam.) Verdc.	Horse gram	Glycine max
Oryza sativa L. (Traditional landraces)	Paddy	High yielding varieties of *Oryza sativa*
Panicum miliaceum L.	Proso millet	High yielding varieties of *Oryza sativa*
Perilla frutescens (L.) Britton.	-	*Glycine max*
Setaria elatica	Foxtail millet	*Glycine max* and *Cajanus cajan*
Triticum aestivum L. (Traditional landraces)	Wheat	High yielding variety of *Triticum aestivum*
Vigna angularis (Willd.) Ohwi & H. Ohashi	Adjuki bean	*Cajanus cajan*
Vigna mungo (L.) Hepper.	Black gram	*Cajanus cajan*
Vigna radiata (L.) R. Wilczek	Green gram	*Cajanus cajan*
Vigna unguiculata (L.)	Cowpea	*Cajanus cajan*

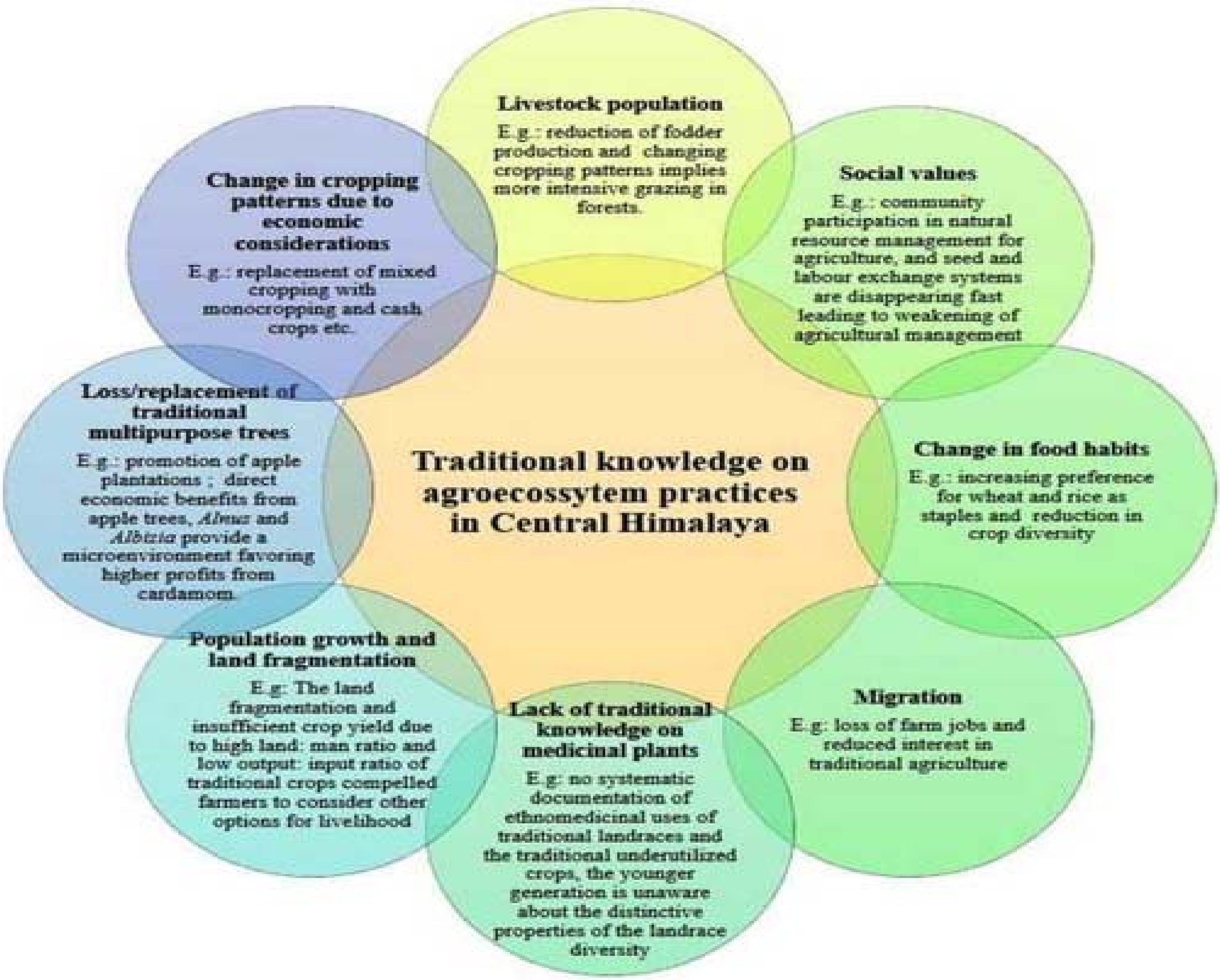

Figure 1. A schematic illustration chart shows different forms of indicators responsible for change in traditional agroecosystem farming system (Adapted from: Chandra et al. 2010).

some of the possible explanations for the existence of remarkable genetic variation of crop varieties in this region.

Agroecosystem management and sustainability

The people living in the mountain ecosysytems in both developed and developing countries, have been dependent on the agrobiodiversity, which is an important sub-set of biodiversity. The maintenance of these agroecosystem with crops their genetic varieties gives a broad range of essential goods and services that support ecosystem functioning, resilience, and productivity (Tilman 2000), and it became a core principle of sustainable agriculture and agro-ecology (Le Coeur et al. 2002). Traditional crop varieties and races are providing food security and nutritional requirement, which evolved over time through trial and error, (Maikhuri et al. 2001, Louette et al. 1997). Toky and Ramakrishnan (1983), Altieri (1995), and Tilman (2000) have described in detail the role of biodiversity and its functions in agro-ecosystem's resilience and stability. The future food supply of the world is entirely depending on the exploitation of genetic diversity (Reid and Miller 1989). At the same time, many of the farmers directly depend on the harvests of genetic diversity for food, fodder, and other economic (Mellas 2000). It is an old insurance policy of farming communities to hedge their risks and plant diverse crops or varieties. The traditional and underutilized crops are ignored and excluded in agricultural policies and programs in the central Himalaya (Maikhuri et al. 2001, Negi and Maikhuri 2012), while crops provide ranges of options to address the complex interface between food insecurity (Fig. 1) and natural resource degradation, allowing coping mechanism specific to the adverse climatic conditions (Maikhuri et al. 1997, 2001, Negi et al. 2009, 2012, 2018). It is now predicted that genetic diversity will be most crucial in highly variable environments and those under rapid human-induced climate change (Hajjar et al. 2008). The adaptability of traditional crops has in fact protected the hill farmers from absolute crop failure since millennia in central Himalaya (Maikhuri et al. 1997, 2001), Nepal (CBS 1996), Ethiopia (Amakele 2005), Mexico (Louette and Smale 2000), Ghana (Anane-Sakyi and Dittoh 2001). Moreover, the by-product yield of the traditional crops is always higher than the high yielding varieties. This becomes significant when the prevailing fodder crisis in the region, particularly up to mid-altitude areas is taken into account (Negi et al. 2010a) for maintaining crop-livestock-manure-soil nutrient cycle of farms in the mountains of the Himalaya. Agrodiversity helps to minimize crop loss due to insect/pests, improves soil fertility by incorporating legumes in the crop mixture, minimizes losses from plant diseases and nematodes, inhibits or suppresses weed growth, increases productivity per unit area, produces a varied diet, possess huge medicinal properties (Farooquee and Maikhuri 2009) as compared to modern agriculture, which greatly relies on external inputs of energy resources. Agricultural intensification has many long-term consequences and creates nutrient imbalances, soil, and water erosion etc. (Maikhuri et al. 1997, Sen et al. 1997). Furthermore, current global production of food is met from traditional multi-cropping systems estimate around 20%, which also help in maintaining ecological equilibrium and sustaining crop gene pool admixtures, transgression, other micro-evolutionary process, etc. (Trupp 1996).

Table 2. Indicators of conservation and sustainable management of traditional ecosystems in Central Himalaya

Indicators for Conservation and Sustainable Management	References
Biomass production	Nisanka and Misra 1990, Chandra et al. 2010, 2011a, Negi et al. 2018
Energy and monetary budgeting	Mitchel 1979, Rapport 1981, Reddy 1981, Bhuller and Mittal 1990, Kumar and Ramakrishnan 1990, Tomar and Tiwari 1990, Giampietro et al. 1992b, Maikhuri and Ramakrishnan 1990, 1992, Singh and Singh 1992, Thakur and Mishra 1993, Franzluebbers and Francis 1995, Rao et al. 2005, Singh et al. 1995, Maikhuri 1992, 1993, 1996, Singh et al. 1997, Tellarini and Caporali 2000, Tripathi and Sah 2001, Mandel et al. 2002, Singh and Sharma 2002, Singh et al. 2002, Gezer et al. 2003, Nihei 2004, Ozkam et al. 2004, Yilmaz et al. 2005, Erdal et al. 2007, Chandra et al. 2011a,b.
Soil and land quality indicators	Maikhuri et al. 1997, Sen et al. 1997, Murage et al. 2000, Lefroy et al. 2000, Chandra et al. 2011b, Negi and Maikhuri 2013
Crop rotation	Moench 1989, Maikhuri and Ramakrishnan 1990, Viglizzo et al. 1991, Singh and Singh 1992a, b, Sundriyal et al. 1994, Mishra and Dash 2000.
Threats and erosion of agrodiversity	Maikhuri et al. 1996, 1997, 2001, Sen et al. 1997, Negi and Maikhuri 2013, Shiva and Vanaja 1993
Socio-economic perspective	Kala 2003, Gairola and Biswas 2008, Nautiyal et al. 2008, Negri et al. 2009, Phondani et al. 2010, Negi and Maikhuri 2013
Religious perspective	Kala 2003, Nautiyal et al. 2008, Phondani et al. 2010, Negi and Maikhuri 2013
Traditional recipes prepared	Maikhuri et al. 1996, 2001, Palni et al. 1998, Nautiyal et al.2005, Bisht et al. 2006
Medicinal use	Kala 2003, Nautiyal et al. 2008, Phondani et al. 2010, Negi and Maikhuri 2013
Ecological and policy related issues	Trupp 1996, Palni et al. 1998, Maikhuri et al. 2000, Jackson et al. 2007, Maikhuri et al. 2009

The assessment of sustainability of agroecosystems requires the development of integrative indicators that take into account the complex interactions between the different socioeconomic and biophysical determinants of agroecosystem structure and function. The major indicators identified for assessing sustainability of the agroecosystem in mountain region of central Himalaya are biomass production; energy and monetary budgeting; soil and land quality indicators; crop rotation; threats and erosion of agrodiversity; socio-economic perspective; religious perspective; used in traditional recipes; medicinal use; ecological and policy related issues (Table 2).

Biomass

Biomass production and consumption patterns were used by Nisanka and Misra, (1990) to analyze the biomass flow between cropland, grassland and plantations and the ecological status of the village landscape. The shortcomings of this approach are obvious as it gives only static information and does not identify the ecologically or socio-economically detrimental processes.

Energy and monetary budgeting

These parameters have been frequently used as a measure of agroecosystem performance, elucidating the pattern of transfer between various compartments and covering the broader aspects of efficiencies achieved during conversion of available resources to output and the net economic benefit they confer. Energy and monetary budget analysis have been applied for comparative analysis of cropping systems and for ascertaining the external energy flows in the form of natural or fossil fuel-based subsidies needed to sustain a specific system thus serving a predictive purpose (Sharma 1991, Singh et al. 1997). However, these indicators may be limited in their scope, being too simplistic in their approach. Energy measures of resources may be at variance with the perceived value of that resource with respect to the role it plays in directing the allocation of resources between alternate uses. Likewise, monetary indicators may underscore the value of reusable resource, thus presenting a distorted illustration of the production from a given system (Mitchel 1979, Rapport 1981, Reddy, 1981, Bhuller and Mittal, 1990, Kumar and Ramakrishnan 1990, Tomar and Tiwari 1990, Giampietro et al. 1992b, Maikhuri and Ramakrishnan 1990, 1992, Singh and Singh 1992, Thakur and Mishra 1993, Franzluebbers and Francis 1995, Rao et al. 2005, Singh et al. 1995, Maikhuri, 1992, 1993, 1996, Singh et al. 1997. Tellarini and Caporali, 2000, Tripathi and Sah, 2001, Mandel et al. 2002, Singh and Sharma, 2002, Singh et al. 2002, Gezer et al. 2003, Nihei 2004, Ozkam et al. 2004, Yilmaz et al. 2005, Erdal et al. 2007, Chandra et al. 2011a;b).

Soil quality

This has also been used as an indicator of agroecosystem sustainability as soil status affects all spheres of agroecosystem productivity (Murage et al. 2000). Farmyard manure (FYM) is one of the most useful and significant indigenous methods practiced in the Central Himalayan village ecosystem. Bedding materials i.e., crop residues and leaf litter are spread in the animal shed and are mixed with dung and urine, which after decomposition is finally converted into FYM (Chandra et al. 2011b, Negi and Maikhuri 2013).

Land quality

This indicator which have added upon basic soil quality measures include criteria such as climate and cropping system provide a much more holistic approach to evaluation of condition and capacity of land to provide services on a sustained basis. Bindraban et al. (2000) proposed the application of yield gap analysis and soil nutrient balance analysis as two-land quality measures which reflect the ecological status as well as the potential of achieving optimum production from land. While soil nutrient balance can identify the detrimental processes and locate deteriorating nutrient stocks, yield gap analysis gives a measure of the gap between the actual realized cereal yield and one that can be achieved under optimum and a range of stressful conditions. A major limitation with which these indicators suffer is their inability to register and reflect the socioeconomic perception and response. They do not take into account the biotic stresses related to management practices and may not be appropriate in areas where cereals are not the dominant crop. Drawing detailed biophysical and socioeconomic information collected at village as well as the household level from several villages, Lefroy et al. (2000) developed qualitative and quantitative indicators for sustainable land management that extended over the five fundamental themes connected to land sustainability viz. productivity, security, protection, viability and acceptability. Feedback from the farmers reinforced the validity of these indicators, although the researchers acknowledged the need to develop more composite indicators that are poorly correlated to other indicators but nevertheless are sensitive to changes in management.

Crop rotation

The farmers of the Central Himalaya have evolved various types of crop rotations in consonance with the varied environmental conditions and agronomic requirements. In such ecosystems, human labour is the main energy input (Ravelle 1976, Mitchell 1979, Nayak et al. 1993) and many other activities such as land use pattern, animal husbandry, domestic subsystem and forest ecosystem (Moench 1989, Maikhuri and Ramakrishnan 1990, Viglizzo et al. 1991, Singh and Singh 1992 a, b, Sundriyal et al. 1994, Mishra and Dash 2000). Traditional farmers respond to change in socio-ecological; religious perspective and environmental conditions through minor/major adjustments in land use strategies resulting in reallocation of inputs and changes in cropping patterns. In marginal environments, such as Himalaya, where integration into mainstream social setup and market economy has been only partial, limited buffering capacity against environmental risk and market uncertainties fosters maintenance of traditional, subsistence oriented cropping systems together with adoption of altered/ new agricultural practices in response to emerging commercial opportunities rather than a radical transformation of traditional subsistence farming to commercial farming as observed in areas like Indo-Gangetic plains. They are now on the verge of destruction or elimination due to rapid loss of forests and crop landraces (Chandra 2007, Chandra et al. 2011a).

Socio-ecological and religious perspective

Farmer's behaviour such as socio-economic, religious perspective; ecological and policy related issues responsible for erosion as well as conservation of traditional landraces. The traditional agrodiversity in Himalayan landscape would be difficult to conserve without conserving the socio-cultural values of the people living in the region along with proper documentation of traditional ecological knowledge pertaining to local available biological resources. Collective knowledge of biodiversity and management are ecological indicators of conservation i.e. cultural diversity; conversely, conserving biodiversity often helps in strengthening the cultural integrity and values (Negi and Maikhuri 2013). The findings of interaction with formers indicate that although in the recent years the crop diversity has declined to an alarming proportion on one hand but other side every farmer of survey villages still cultivating all traditional crops for their cultural and ritual purposes. There exists a symbiotic relationship between biological diversity and cultural diversity as well as in between habitat and cultures (Nautiyal et al. 2008, Negri et al. 2009). Every cultivator offers the produce to the god and goddess of the village before consuming and selling the produce. The indigenous flora utilized by the communities has substantial influences on their culture, customs, craftsmanship, ethos, religious rites, socio-cultural beliefs, food habits, settlement patterns, and various other resource-based practices (Gairola and Biswas 2008). The head of village representative collects a specific quantity of recently harvested crops from every household and offers it to the god and goddess. List of some important crops along with socio-cultural and medicinal value is shown in Figure 1 (Nautiyal et al. 2008). There are many such festivals organized every year to conserve the agrodiversity in central Himalaya i.e., Harela festival and Hariyali festival. Among various, Hariyali festival is celebrated in the Kedarnath valley, in which the seedlings of Jau (*Hordeum vulgare*) tested before the god and the seedling offers to each family of the village having the wish of agrodiversity prosperity. With better growth of Harela crops it can be presumed/predicted that all the crops would give better production and the demand of the local people. Offerings are made for better crop production, conservation, and prosperity. In the Kumaon region of the Central Himalaya, Harela is an integral part of cultural activity and is celebrated with religious fervor and gaiety (Nautiyal et al. 2008). Traditional agrodiversity management is one of example of diversification of food items, and value additions in local recipes are of paramount importance to secure the food availability (Chandra et al. 2011, Negi and Maikhuri 2013). If attention is not paid to such cultural practices of biodiversity conservation, then the cultural diversity-based traditional agrodiversity management will vanish from the region (Maikhuri et al. 1996, 2001, Palni et al. 1998, Nautiyal et al. 2005, Bisht et al. 2006, Chandra et al. 2010).

Medicinal value of traditional crops

The traditional values and indigenous knowledge of the healthcare system of the traditional crops are important for their traditional agrodiversity management in the central Himalayan village ecosystem. The traditional crop varieties are not only a good source of food and nutrition, but also are used in the treatment of various diseases in the region

Table 3 Traditional crop species along with their socio-cultural, medicinal value and used in traditional recipes in Central Himalaya

Crop species	**Socio-ecological perspective**	**Medicinal use**
Amaranthus spp.	Roasted seeds offered to lord Shiva	The husk of the grains is used to cure skin diseases.
Oryza sativa	Traditional recipes offered to god	Rice mixed with pulses to prepare a traditional dish Khichdi, provided to the patient suffering from intestinal pain.
Triticum aestivum	‘‘Mungi’’ prepared from immature grain offered to god for better yield	Paste of grain applied on burn.
Hordeum vulgare	Seeds are used in “Havan”. Seedling used to germinate to offer god during many religious celebrations	Improve digestion.
Fagopyrum esculentum	Traditional recipe used during fast	The grains are used to cure fever and all kinds of abdominal ailments.
Fagopyrum tataricum	Traditional recipe used during fast	Leaves are used in the treatment of fever and headache.
Eleusine coracana	‘‘Maduva ki Roti’’ is symbol of traditional culture.	“Roti” is provided to the patient to improve digestion and avert cold.
Setaria italica	“Kheer” is symbol of traditional culture.	“Kheer” provided to the patient suffering from typhoid and pneumonia.
Sesamum indicum	Seeds are used in religious rituals like Havan with barley and ghee.	Seed oil used to cure muscular pain and applied on the body of the patient suffering from measles.
Perilla frutescens	Traditionally seed oil used by local women of the region for massaging new born infants.	The leaves are used in the treatment of colds, vomiting and abdominal pain.
Vigna mungo	‘‘Pakodi’’ prepared during many cultural celebration.	‘‘Khichra’’ is offered to forest god against evil spirit. Paste of seeds used to plaster on fractured part of body.
Glycine max	Traditional ‘‘Roti’’ prepared with *Elusine coracana*.	Seeds are used to cure common cold.
Macrotyloma uniflorum	It is known to be a good and nutritious pulse.	Useful to cure kidney stone.
Vigna unguiculata	‘‘Pakoda’’ prepared during cultural celebration.	Boiled soup with salt used to cure chickenpox.
Glycine soja	‘‘Bhattwani’’ prepared during cultural celebration and auspicious occasion.	During winters roasted seed is consumed to maintain body temperature and cure common cold.
Brassica campestris	Oil of *B. campestris* considered as pure for lighting lamp during worship.	Edible oil is preferred for good health.

(Table 3). In addition to this, all the crops have strong socio-cultural/religious value and used in worship during many ceremonies and festivals. Farmers of the region possess enough knowledge about various crop resources and wild edibles for their subsistence need and other uses (Bisht et al. 2006, Negi et al. 2010b). Traditional herbal remedies have always played a key role in the healthcare systems, all over the world (Kala 2003). Thus, it is important to document and revitalize the indigenous knowledge system. Knowledge, innovations, and practices of indigenous and local communities that are collectively linked to traditional resources and the diversity of genes, varieties, species, and ecosystems, and the cultural and spiritual values within the socio-ecological and religious perspective of communities need to protected (Kala 2003, Phondani et al. 2010, Negi and Maikhuri 2013). The need for preservation, protection, and promotion of traditional knowledge has become inevitable for self-sustenance, the economic prosperity of knowledge holders, and competitive business advantage (Ceccarelli et al. 2007, Cavatassi et al. 2011), however, very essential for value addition to local landrace diversity and sustaining the agroecosysetm in Central Himalaya.

CONCLUSIONS

Socio-ecological and religious perspective approach to conservation and sustainable management of local communities are complementary functions of traditional ecosystems in Central Himalaya. However, environmental perturbations and socio-ecological changes are a major cause of the replacement of some traditional crop varieties by high yielding varieties in the region. Among the other causes responsible for erosion of traditional ecosystems in Central Himalaya are (i) loss of traditional knowledge, (ii) change in cropping patterns due to economic considerations, (iii) population growth and land fragmentation, (iv) loss/ replacement of traditional multipurpose trees (v) out-migration of working force, (vi) change in food habits, and (vii) decline in livestock population. Therefore, traditional system of cropping and traditional varieties/landraces, and also cultural activities that support conservation of agrodiversity need to be popularized at the regional and national level. This ecologically well tested practices in the region needs to be supported through government development programs. This study recommended conservation of traditional crop diversity and sustainable land use development through institutional and policy support in the Himalayan region. There are many studies on the sustainability of agriculture system of this region, only needs to follow the right policies and management strategies taking consideration of scientific studies.

ACKNOWLEDGEMENTS

The authors are thankful to the Forest Department of Uttarakhand for the permissions and help in collecting data.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AC and KSR designed manuscript. AC wrote the paper and VSN, LSK, JD, RKM help in editing the manuscript and finalizing the paper.

REFERENCES

Altieri, M. 1995. Agro-ecology puts synergy to create self-sustaining agro ecosystem. Ceres FAO Review, 154 (27A), 5–23.

Amakele, T. 2005. Food security monitoring and early warning: An integrated analytical approach for food security monitoring, early warning and emergency need assessment based on the Ethiopian experience. (M.A. Thesis). Tufts University. Friedman School of Nutrition Science and Policy.

Anane-Sakyi, C. and Dittoh, S. 2001. Agro-biodiversity conservation: Preliminary work on in situ conservation and management of indigenous rice varieties in the interior savanna zone of Ghana. PLEC News & Views, 17, 31–33.

Anthwal, A., Sharma, R.C. and Sharma, A. 2006. Sacred groves: Traditional way of conserving plant diversity in Garhwal Himalaya, Uttaranchal. American Journal of Science, 2(1), 35-38.

Bhuller, B.S. and Mittal, J.P. 1990. Energy requirements for wheat production in a selected village of Punjab. Journal Rural Technology, 2, 9-22.

Bindraban, P.S., Stoorvogel, J.J., Jansen, D.M., Vlaming, J. and Groot, J.J.R. 2000. Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. Agriculture, Ecosystem and Environment, 81, 103-112.

Bisht, I.S., Rao, K.S., Bhandari, D.C., Nautiyal, S., Maikhuri. R.K. and Dhillon, B.S. 2006. A suitable site for in-situ (on-farm) management of plant diversity in traditional agroecosystems of western Himalaya in Uttaranchal state: A case study. Genetic Resources and Crop Evolution, 53, 1333–1350.

Cavatassi, R., Lipper, L. and Narloch, U. 2011. Modern variety adoption and risk management in drought prone areas: Insights from the sorghum farmers of eastern Ethiopia. Agricultural Economics, 42(3), 279–292.

CBS. 1996. Nepal Living Standards Survey Report (Vol. I & II). Kathmandu: Central Bureau of Statistics.

Ceccarelli, S., Grando, S. and Baum, M. 2007. Participatory plant breeding in water-limited environments. Experimental Agriculture, 43(4), 1–25.

Chandra, A. 2007. Traditional Agrodiversity Management in Central Himalayan Village Ecosystem. Ph.D. Thesis, University of Delhi, Delhi, India.

Chandra, A. and Rao, K.S. 2007. In-situ conservation of local landraces of *Oryza sativa* L. and *Triticum aestivum* L. in Garhwal: A case study from Central Himalaya, India, Environment and We International Journal of Science and Technology, 2, 1-7.

Chandra, A., Kandari, L.S., Negi, V.S., Maikhuri, R. K. and Rao, K.S. 2013. Role of intercropping on production and land use efficiency in the Central Himalaya, India. Environment and We International Journal of Science and Technology, 8, 105-113.

Chandra, A., Kandari, L.S., Payal, K.C., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2010a. Conservation and sustainable management of traditional ecosystems in Garhwal Himalaya, India. New York Science Journal, 3(2), 71-77.

Chandra, A., Kandari, L.S., Rao, K.S., Saxena, K.G. 2011b. Assessment of Socio-Economical Status and its Impact on Land Use Management in Central Himalaya. Asian Journal of Agricultural Research, 5(4), 234-242.

Chandra, A., Pardha-Saradhi, P., Maikhuri, R.K., Saxena, K.G. and Rao, K.S. 2011a. Traditional agrodiversity management: A case study of Central Himalayan village ecosystem. Journal of Mountain Science, 8, 62-74.

Chandra, A., Pardha-Saradhi, P., Maikhuri, R.K., Saxena, K.G. and Rao, K.S. 2010b. Assessment of monetary budget in traditional agrodiversity management: A case study of Central Himalayan village ecosystem. Phytomorphology, 60 (3-4), 137-149.

Chandra, A., Pardha-Saradhi. P., Rao, K.S., Saxena, K.G. and Maikhuri, R.K. 2011c. An investigation into the energy use in relation to yield of traditional crops in Central Himalayas, India. Biomass and Bioenergy, 35, 2044-2052.

Chapin, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D. U., Lavorel, S. Sala, O.E., Hobbie, S.E., Mack, M.C. and Díaz, S. 2000. Consequences of changing biodiversity. Nature, 405, 234–242.

Dhyani, S., Maikhuri, R.K. and Dhyani, D. 2011. Energy budget of fodder harvesting pattern along the altitudinal gradient in Garhwal Himalaya, India. Biomass and Bioenergy, 35(5), 1823-1832.

Erdal, G., Esengua, K., Erdal, H. and Gunduz, O. 2007. Energy use and economic analysis of sugarbeat production in Tokat province of Turkey. Energy, 32, 35-41.

FAO. 2004. The State of Food Insecurity in the World. Food and Agriculture Organization of the United Nations, Rome, Italy. ISBN: 92-5- 105178-X.

Farooquee, A.N. and Maikhuri, R.K. 2009. Communities and their agrobiodiversity priorities for agriculture in Uttarakhand Himalaya, India. Outlook on Agriculture, 38(4), 383–389.

Franzluebbers, A.J. and Francis, C.A. 1995. Energy output-input ratio of maize and sorghum management systems in Eastern Nebraska. Agriculture, Ecosystem and Environment, 53, 271-278.

Gairola, Y. and Biswas, S. 2008. Bioprospecting in Garhwal Himalayas, Uttarakhand. Current Science, 94(9), 1139–1143.

Gezer, I., Acaroglu, M. and Haciseferogullari, H. 2003. Use of energy and labour in apricot agriculture in Turkey. Biomass and Bioenergy, 24, 215-219.

Giampietro, M., Cerretelli, G. and Pimental, D. 1992b. Energy analysis of agricultural ecosystem management: human return and sustainability. Agriculture, Ecosystem and Environment, 37, 219-244.

Hajjar, R., Jarvis, D.I. and Gemmill-Herren, B. 2008. The utility of crop genetic diversity in maintaining ecosystem services. Agriculture, Ecosystem and Environment, 123, 261–270.

Ives, J.D. and Messerli, B. 1989. The Himalayan Dilemma: Reconciling Development and Conservation. Routledge, London.

Jarvis, D.I., Myer, L.H., Klemick, L., Guarino, M., Brown, A.H.D., Sadiki, M., Sthapit, B. and Hodgkin, T. 2000. A training guide for in-situ conservation on-farm. Version 1. Rome, Italy: International Plant Genetic Resources Institute.

Kala, C.P. 2003 Indigenous uses of plants as health tonic in Uttaranchal Himalaya. India. Annals of Forestry, 11(2), 249–254.

Kandari, L.S., Phondani, P.C., Payal, K.C., Rao, K.S. and Maikhuri, R.K. 2012. Ethnobotanical study towards conservation of medicinal and aromatic plants in upper catchments of Dhauli Ganga in the Central Himalaya. Journal of Mountain Science, 9, 286-296.

Koirala, G.P. and Thapa, G.B. 1997. Food Security Challenges: Where Does Nepal Stand? Research Report Series No. 36. Kathmandu: Winrock International.

Kumar, A. and Ramakrishnan, P.S. 1990. Energy flow through an Apatani village ecosystem of Arunachal Pradesh in North East India. Human Ecology, 18, 315-336.

Kumar, B., Chandra, S., Bargali, K. and Pangtey, Y.P.S. 2007. Ethnobotany of religious practicies of Kumaun (Havan). Dehradun: Bishan Singh Mahendra Pal Singh. 137pp.

LeCoeur, D., Baudry, J. and Burel, F. 2002. Why and how we should study field boundary biodiversity in an agrarian landscape. Agriculture, Ecosystem and Environment, 89, 23–40.

Lefroy, R.D.B., Bechstedt, H.D. and Rais, M. 2000. Indicators for sustainable land management based on farmer surveys in Vietnam, Indonesia, and Thailand. Agriculture, Ecosystem and Environment, 81, 137-146.

Louette, D. and Smale, M. 2000. Farmers' seed selection practices and traditional maize varieties in Cuzalapa, Mexico. , 113, 25–41.

Louette, D., Charrier, A. and Berthaud, J. 1997. *In-situ* conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community. Economic Botany, 51, 20–38.

LRMP. 1996. The Land Resource Mapping Project, Land Systems: Land Utilization and Agriculture and Forestry Reports, Canada: Kenting Earth Science.

Maikhuri, R.K. 1992 Eco-energetic analysis of animal husbandary in traditional societies of India. Energy, 17, 957-967.

Maikhuri, R.K. 1993. Evaluation of some multipurpose trees in traditional agroecosystems of Garhwal Himalaya, India. Nitrogen Fixation Tree Assocosiatin Journal, 11, 11-23.

Maikhuri, R.K. 1996. Eco-energetic analysis of village ecosystem of different traditional societies of north-east India. Energy, 21, 1287-1297.

Maikhuri, R.K. and Ramakrishnan, P.S. 1990. Ecological analysis of a cluster of villages emphasizing land use of different tribes in Meghalaya in north-east India. Agriculture, Ecosystem and Environment, 31, 17-37.

Maikhuri, R.K. and Ramakrishnan, P.S. 1992. Comparative analysis of the village ecosystem functions of different tribes living in the same area of Arunachal Pradesh in north-eastern India. Agriculture System, 35, 377-399.

Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 1996. Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. International Journal of Sustainable Development and World Ecology, 2, 1–24.

Maikhuri, R.K., Rao, K.S. and Semwal, R.L. 2001. Changing scenario of Himalayan agroecosystems: Loss of agrobiodiversity, an indicator of environmental change in Central Himalaya, India. The Environmentalist, 21, 23–39.

Maikhuri, R.K., Rawat, L.S., Negi, V.S., Faroouquee. N.A., Rao, K.S., Purohit, V.K., Agarwal, S.K., Chamoli, K.P., Negi, C.S., Saxena, and K.G. 2011. Empowering rural women in agro-ecotechnologies for livelihood improvement and natural resource management. Outlook on Agriculture, 40(3), 229–236.

Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1997. Eroding traditional crop diversity imperils the sustainability of agriculture systems in Central Himalaya. Current Science, 73(9), 777–782.

Mandal, K.G. Saha, K.P. Ghosh, P.K., Hati, K.M. and Bandyopadhyay, K.K. 2002. Bioenergy and economic analysis of soybean-based crop production systems in Central India. Biomass and Bioenergy, 23, 337-345.

Mellas, H. 2000. Morocco. Seed supply systems: Data collection and analysis. Pp. 155-156, In Jarvis, D., Sthapit, B. and Sears, L. (Eds.), Conserving Agricultural Biodiversity in situ: A Scientific Basis for Sustainable Agriculture. Rome: FAO.

Mishra, M.K. and Dash, S.S. 2000. Biomass and energetic of non-timber forest resources in a cluster of tribal villages on the Eastern Ghats of Orissa, India. Biomass and Bioenergy, 18, 229-247.

Mitchell, R. 1979. The Analysis of Indian Agro-ecosystems. Inter print, New Delhi, India.

Moench, M. 1989. Forest degradation and the structure of biomass utilization in a Himalayan foothills village. Environmental Conservation, 6, 137-146.

Mohamad Saleem, M.A. 1998. Nutrient balance patterns in African livestock system. Agriculture, Ecosystem and Environment, 71, 241-254.

Murage, E.W., Karanja, N.K., Smithson, P.C. and Woomer, P.L. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Highlands. Agriculture, Ecosystem and Environment, 79, 1-8.

Nautiyal, S. and Kaechele, H. (2007) Conservation of crop diversity for sustainable landscape development in the mountains of the Indian Himalayan region. Management of Environmental Quality: An International Journal, 18(5), 514-530.

Nautiyal, S., Bisht, V., Rao, K.S. and Maikhuri, R.K. 2008. The role of cultural values in agrobiodiversity conservation: A case study from Uttarakhand, Himalaya. Journal of Human Ecology, 23(1), 1-6.

Nautiyal, S., Maikhuri, R.K., Rao, K.S., Semwal, R.L., and Saxena, K.G. 2003. Agroecosystem function around a Himalayan Biosphere Reserve. Journal of Environmental Systems, 29, 71-100.

Nautiyal, S., Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1998. Agroforestry system in the rural landscape-a case study in Garhwal Himalaya, India. Agroforestry System, 41, 151-165.

Nautiyal, S., Rajan, K.S. and Shibasaki, R. 2005 Interaction of biodiversity and economic welfare-a case study from Himalayas of India. Journal of Environmental Informatics, 6(2), 111–119.

Nautiyal, S., Rao, K.S., Maikhuri, R.K., Negi, K.S. and Kala, C.P. 2002. Status of medicinal plants on way to Vasukital in Mandakini valley, Garhwal Himalaya, Uttaranchal. Journal of Non-Timber Forest Products, 9 (3/4), 124-131.

Nayak, S.P., Nisanka, S.K. and Mishra, M.K. 1993. Biomass and energy dynamics in tribal village ecosystem of Orissa, India. Biomass and Bioenergy, 4, 23-24.

Negi, V.S. and Maikhuri R.K. 2013. Socio-ecological and religious perspective of agrobiodiversity conservation: Issues, concern and priority for sustainable agriculture, Central Himalaya. Journal of Agricultural and Environmental Ethics, 26, 491–512

Negi, V.S., Maikhuri, R.K. and Rawat, L.S. 2012. Paradigm and Ecological Implication of Changing Agricultural Land-use: A Case Study from Govind Wildlife Sanctuary, Central Himalaya, India. Journal of Mountain Science, 9, 547–557.

Negi, V.S., Maikhuri, R.K., Chandra, A., Maletha, A. and Dhyani, P.P. 2018. Assessing sustainability of farming systems in mountain agroecosystems of Western Himalaya, India. Agroecology and Sustainable Food Systems, 42(7), 751-776.

Negi, V.S., Maikhuri, R.K., Rawat, L.S. and Bahuguna, A. 2009. Traditional agriculture in transition: A case of Harki Doon Valley (Govind Pashu Vihar sanctuary and national park) in Central Himalaya. International Journal of Sustainable Development and World Ecology, 16(5), 313–21.

Negi, V.S., Maikhuri, R.K., Rawat, L.S. and Phondani, P.C. 2010a. An inventory of indigenous knowledge and cultivation practices of medicinal plants in Govind Pashu Vihar wildlife sanctuary, Central Himalaya, India. International Journal of Biodiversity Science, Ecosystem Services, 6(3&4), 96–105.

Negi, V.S., Maikhuri, R.K., Rawat, L.S. and Vashishtha, D.P. 2010b. The livestock production system in a village ecosystem in the Rawain valley, Uttarakhand, Central Himalaya. International Journal of Sustainable Development and World Ecology, 17(5), 431–438.

Negri, V., Maxted, N. and Vetelainen, M. 2009. European landrace conservation: An introduction. In Vetelainen, M.V., Negri, V. and Maxted, N. (Eds.), European Landraces: On-farm Conservation, Management and Use. Biodiversity Technical Bulletin No.15. Rome, Italy: Biodiversity International.

Nihei, T. 2004. Classification of agricultural regions by means of input-output energy ratio. Tsukuba Daigaku Jinbun Chirigeku Kenkyu, 28, 77-90.

Nisanka, S.K. and Misra, M.K. 1990. Ecological study of an Indian village ecosystem: Biomass production and consumption. Biomass, 23, 117-136.

Ozkam, B., Kurklu, A. and Akeaz, H. 2004. An input-output energy analysis in green house vegetable production: A case study for Antalya region of Turkey. Biomass and Bioenergy, 26, 89-95.

Palni, L.M.S., Maikhuri, R.K. and Rao, K.S. 1998. Conservation of the Himalayan agroecosytstems: Issues and priorities. Technical Paper V. pp. 253-290. In: Eco-regional co-operation for biodiversity conservation in the Himalaya. Kathmandu: UNDP.

Phondani, P.C., Maikhuri, R.K., Rawat, L.S., Farooquee, N.A., Kala, C.P., Vishvakarma, S.C.R., Rao, K.S. and Saxena, K.G. 2010. Ethnobotanical uses of plants among Bhotiya Tribal communities of Niti valley in central Himalaya, India. Ethnobotany Research and Application, 8, 233–244.

Pilbeam, C.J., Tripathi, B.P., Sherchan, D.P., Gregory, P.J. and Gaunt, J. 2000. Nitrogen balances for households in the mid-hills of Nepal. Agriculture Ecosystem and Environment, 79, 61-72.

Powell, J.M., Fernandez_Rivera, S., Hiernaux, P. and Turner, M.D. 1996. Nutrient cycling in integrated rangeland/cropland systems of the Sahal. Agricultural Systems, 52, 143-170.

Rao, K.S., Nautiyal, S., Maikhuri, R.K. and Saxena, K.G. 2005 Resource flows of villages with contrasting lifestyles in Nanda Devi Biosphere Reserve, Central Himalaya, India. Journal of Mountain Science, 2, 271-293.

Rapport, R.A. 1971. The flow of energy in an agricultural society. Scientific American, 255, 116-132.

Ravelle, R. 1976. Energy use in rural India. Science, 192, 969-975.

Reddy, A.K.N. 1981. An Indian village agricultural ecosystem-case study of Ungra village. Biomass, 1, 77-88.

Reid, W.V. and Miller, K.R. 1989. Keeping Options Alive: The scientific basis for conserving biodiversity. Washington D.C.: World Resources Institute.

Saxena, K.G., Maikhuri, R.K. and Rao, K.S. 2005. Changes in agricultural biodiversity: Implications for sustainable livelihood in the Himalaya Journal of Mountain Science, 2, 23-31.

Saxena, K.G., Rao, K.S., Sen, K.K., Maikhuri, R.K. and Semwal, R.L. 2001. Integrated natural resource management: approaches and lessons from the Himalaya. Conservation Ecology, 5, 14.

Scoones, I. and Toulmin, C. 1998. Soil nutrient balances: what use for policy? Agricultural Ecosystem Environment, 71, 255-267.

Semwal, R.L., Nautiyal, S., Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agriculture, Ecosystems & Environment, 102, 81–92.

Sen, K.K., Rao, K.S. and Saxena, K.G. 1997. Soil erosion due to settled upland farming in Himalaya: A case study in Pranmati. International Journal of Sustainable Development and World Ecology, 4, 65–74.

Sen, K.K., Senwal, R.L., Rana, U., Nautiyal, S., Maikhuri, R.K., Rao, K.S., and Saxena, K.G. 2002. Patterns and implications of land use/cover change: a case study in Pranmati watershed (Garhawal Himalaya, India). Mountain Research and Development, 22, 56–62.

Sharma, S. 1991. Energy budget studies of some multiple cropping patterns of the central Himalaya. Agriculture Ecosystem and Environment, 36, 199-206.

Sherchand, D.P., Pilbeam, C.J. and Gregory, P.L. 1999. Response of wheat/rice and maize/millet system to fertilizer and manure applications in mid-hills of Nepal. Experimental Agriculture, 35, 1-13.

Shiva, V. and Vanaja, R.P. 1993 Cultivating diversity: Biodiversity conservation and seed policies. Research Foundation for Science Technology and Natural Resource Policy. Dehradun, India: Natraj Publishers. 130pp.

Singh, A., Reddy, V.S. and Singh, J.S. 1995. Analysis of woody vegetation of Corbett National Park, India. Vegetatio, 120, 69-79.

Singh, G.S., Rao, K.S. and Saxena, K.G. 1997. Energy and economic efficiency of the mountain farming system: a case study in the north-western Himalaya. Journal of Sustainable Agriculture, 9, 25-49.

Singh, H., Mishra, D. and Nahar, N.M. 2002. Energy use pattern in production agriculture of a typical village in Arid zone India. Energy Conversion and Management, 43, 2275-2286.

Singh, J.S. and Singh, S.P. 1992a. Forests of Himalaya: Structure, Functioning and Impact of Man. Gyanodaya Prakashan, Nainital.

Singh, S. and Singh, G. 1992b. Energy input crop yield relationship for four major crops of northern India. Agricultural Mechanization in Asia, Africa and Latin America, 23, 57-61.

Singh, V.K. and Sharma B.B. 2002. Economic evaluation of rice (Oryza sativa) based cropping sequences in the foothills of Himalayas. Indian Journal of Agronomy, 47, 12-19.

Sundriyal, R.C., Rai, S.C., Sharma, E. and Rai, Y.K. 1994. Hill Agroforestry systems in south Sikkim, India. Agroforestry System, 26, 215-235.

Tellarini, V., Caporali, F. 2000. An input/output methodology to evaluate farms as sustainable agroecosystems: an application of indicators to farms in central Italy. Agriculture, Ecosystem Environment, 77, 111-123.

Thakur, C.L. and Mishra, B.L. 1993. Energy requirement and energy gaps for production of major crops in Madhya Pradesh. Agricultural Situation in India, 48, 665-689.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. Nature, 405, 208–211.

Toky, O.P. and Ramakrishnan, P.S. 1983. Secondary succession following slash and burn agriculture in north-eastern India. I. Biomass, litterfall and productivity. Journal of Ecology, 72, 735–745.

Tomar, S.S. and Tiwari, A.S. 1990. Production potential and economics of individual crop sequence. Indian Journal of Agronomy, 35, 30-35.

Tripathi, R.S. and Sah, V.K. 2001. Material and energy flows in high-hill, mid-hill and valley farming systems of Garhwal Himalaya. Agriculture, Ecosystem Environment, 86, 75-91.

Trupp, L.A. 1996. Linking Biodiversity and Agriculture. New York: World Resource Institute's Publication.

Turner, D.M. 1996. Natural product source material use in the pharmaceutical industry: the Glaxo experience. Journal of Ethanopharmacology, 51, 39-43.

Van Faasson, H.G. and Lebbink, G. 1994, Organic matter and nitrogen dynamics in conventional versus integrated arable farming. Agriculture, Ecosystem Environment, 51, 209-226.

Viglizzo, E.F., Roberto, Z.E. and Brockington, N.R. 1991. Agroecosystem performance in semi-arid pampas of Argentina and their interaction with the environment. Agriculture, Ecosystem Environment, 36, 23-26.

Yilmaz, I., Akcaoz, H. and Ozkam, B. 2005. An analysis of energy use and input-output costs for cotton production in Turkey. Renewable Energy, 30, 145-155.

Received:5th August 2021
Accepted:1st September 2021