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Soils of North-Western Himalayan eco-system and their land use, constraints, productivity potentials and future strategies

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Introduction

Hill and mountain eco-system cover a large area (54 M ha) of the country encompassing mainly northern and north-eastern frontier states as well as some parts of central and southern states. The Himalayas represent the youngest mountain range, having been uplifted about 60-70 million years ago. The Himalayas have great influence on the environmental conditions of northern India and the people living in Indo-Gangetic Plains. The complex geological history of the Himalayas and its tectonic stress which heaved up this range has contributed to the aggravating of the earth's dynamic process of weathering, erosion, mass wastage, seismicity, and so on, which affects and modify the natural environment (Dewan and Sharma 1985). The developmental activities *i.e.* construction of high dams, exploration for minerals and mining activities and the quest for arable land for cultivation lead to deterioration and degradation of natural resources like soils, forests, glacial, *etc*. This eco-system remains poorly conceptualized and characterized and needs immediate attention in research and development. Degradation and natural resources due to demographic pressure, diminishing forest covers, increasing population, extinction of diversity and global warming are serious environmental issues. Projections of Soil and Water Conservation Division, Ministry of Agriculture (1994) reveal that out of 107.4 million ha degraded lands in India, 60 ha is seriously affected by water erosion. Hill and mountain ecosystems covering about 54 million ha are highly fragile due to geological, topographical, climatic and demographic reasons, inaccessible rugged terrain, high risk, low pay off, fragmented small farm holdings and multiple ethnicity compounds and complexity of hill and mountain ecosystems (Biswas and Mukherjee 1994). Soils of this ecosystem are less fertile with problems associated with soil acidity, low exchange capacity and aluminum toxicity (Sen *et al*. 1997). These eco-systems have tremendous off-site effect since they regulate floods, droughts, ground water recharge and sediment deposition in reservoirs and flood plains. Hill and mountain eco-systems are also gifted with tremendous opportunities to meet these challenges. These ecosystems have rich biodiversity and highly potential productivity and regulate hydrology of river basins. Hill and mountain region, soils are considered as the integral part of the landscape and their characteristics are largely governed by the landform (Sawhney *et al.* 2000).The impact of physiographic factors such relief, slope and altitude are strikingly apparent in soil formation in hilly region (Gupta and Chera 1996). The variation in soils is mainly associated with altitude, land use, and (Walia *et. al*. 1999). Though number of literature is available on soil resources and related aspects in this tract in form research papers, reports, bulletins (Dewan and Sharma 1985; Sidhu *et al*. 1987, 1995, 1997, 1998, 2000, 2007, 2008, 2009, 2010, 2013; Sidhu and Rana 2010; Sidhu and Jain 1993; Karan Singh *et al*. 1992, 1993; Kirmani *et al*. 2013; Mahapatra *et al*. 2000a&b; Rana *et al*. 2000; Sehgal 1973; Sehgal *et al*. 1985, 1989, 1993; Staff NBSSLUP 1992, 1998; Verma *et al*. 1999) but the comprehensive information about the characteristics and classification of soils of hill and mountain ecosystem their land use, constraints, potentials at one source is lacking. The present status of soil

resource information of fragile north-western Himalayan range is very essential for many developmental projects and also useful for appropriate land use plans and other opportunities; and is therefore a key to translate this database into opportunities for judicious land use. Hence keeping above points in view, the present paper focused on the distribution and kind of soils, their problems and potentials and land use options in different landforms of Himalayas in northern region of the country across the hilly states Jammu & Kashmir (J&K), Himachal Pradesh (H.P.) and Uttrakhand and northern fringes of adjoining states of Punjab, Haryana and Uttar Pradesh.

Geographic setting of North-Western Himalaya

The Indian Himalayan Region (IHR) is spreading on 10 states (administrative regions) namely, Jammu & Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and hill regions of 2 states *viz*. Assam and West Bengal of Indian Republic (Fig.1). Starting from foothills in the south (Siwaliks) the region extends to Tibetan plateau in the north (trans-Himalaya) comprising about 95 districts of the country. The region occupies the strategic position of entire northern boundary (North-West to North-East) of the nation and touches almost all the international borders (7 countries) with India. It contributes about 16.2 per cent of India's total geographical area, and most of the area is covered by snow-clad peaks, glaciers of higher Himalaya, dense forest cover of mid-Himalaya. The IHR shows a thin and dispersed human population as compared to the national figures due to its physiographic condition and poor infrastructure development but the growth rate is much higher than the national average. In the present paper soil resources of three northern states *i.e*. Jammu & Kashmir, Himachal Pradesh and Uttrakhand and small areas of Punjab, Haryana and Uttar Pradesh have been described

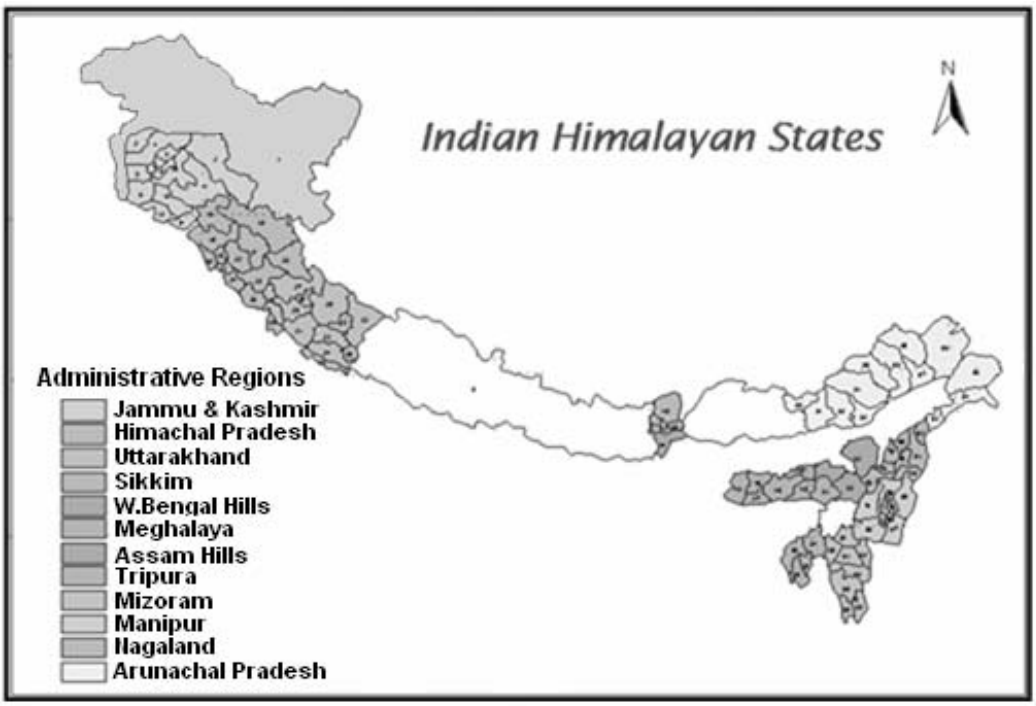

Fig 1. Himalayan system of the country

The North-Western tract of Himalayan system located between 28°43' N to 37°05' N Latitude and 72°02' E to 81°02' E Longitude. This tract covers an area of approximate 33.12 M ha. The climate ranges from cold arid zone to temperate, sub-tropical temperate transitional and low altitude sub-tropical zone. The mean maximum temperature ranges from 12.4 °C in Leh to 30.0 °C in Jammu and 34.5 in Siwaliks and mean minimum temperature from -1.4 °C in Leh to 18.7 °C in Jammu and 5. Rainfall is highly variable from <100 mm in cold desert area to as high as >1600 mm in Uttarakhand region. The temperature regime ranges from Cryic to Hyperthermic and moisture regime from aridic cold in Greater Himalaya to humid in Lesser Himalayas and sub-humid in Siwaliks.

This tract is broadly divided in to three distinct landform units *i.e*. Greater Himalayas, Lesser Himalayas and Siwaliks. These units are sub-divided into 9 sub-units (Fig.2) for more refinement these units are described under each unit while describing the soils as under

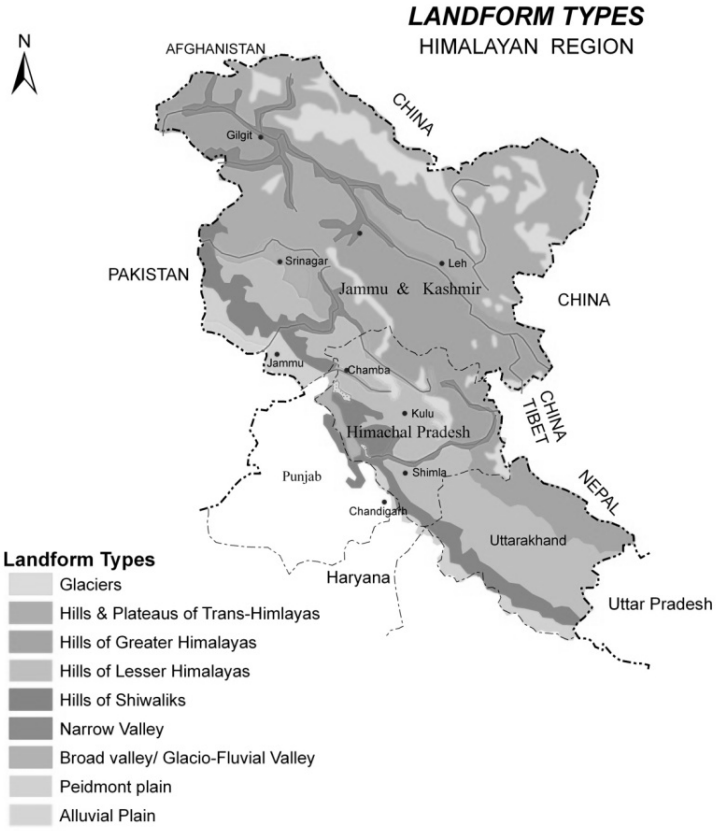

Fig 2. Landform types of Northern region

Soils of Trans/Greater Himalayas

The soils in the Western Himalayas covering eastern aspects of Ladakh plateau, including Leh and surroundings, rages of Karakoram, Ladakh, Zanskar, western half of Ladakh plateau (Leh), Kargil and Gilgit areas of J&K (Rana *et al.* 2000; Sachdev *et al.* 1995; Walia *et al.* 1999; Gawande *et al.* 1979), north-north eastern part of Lahaul-Spiti valley of Himachal Pradesh represent most of the cold desert of the state (Sidhu *et al.* 1995, 1997; Sehgal *et al.* 1993; HPKVV 1991), a northern parts of Uttrakhand bordering Tibet, commonly known as Himadri, (Singh *et al.* 2004). This zone is highly rugged, dissected and difficult with precipitous snow clad slopes, horned peaks, hanging valleys and gi-

gantic escarpments. The relief average between 4800 to 6000 m above MSL but some exceed 7500 m their elevation. Granites, phyllites and mica schists are the major rock formations. The base of the sedimentary column in this region is formed by argillaceous metamorphic, where mica schists, rich in kyanite, staurolite and garnets are predominant. The overlying limestone is exposed at places. The precipitation is received as snowfall during winter. The winter snowfall accompanied by cold climate (as low as -15°C) plays crucial negative role in developing soil profile. However, during the following summer months, the snow melts, resulting in limited weathering and liberation of some bases towards development of B - horizon on favorable topographic position. Sehgal *et al.* (1985), the cool, humid mountain region experience a chrono-sequence of soils from the A-C to a deep A-Bt-C profile. The cold desert areas represent unique climatic conditions with negligible summer monsoon rains and the cold desert region may qualify for Aridic, Xeric or Udic moisture regime (Sehgal 1973). Sehgal *et al*. (1993) further refined the climatic data of this tract and classified as Cryic and Cryic-like Mesic and Mesic temperature regimes. These soils pertain to AER 1 (Western Himalayas Cold Arid Eco region), AESR 1.1 (Ladakh plateau cold, hyper arid eco-sub region) and 1.2 (western aspects of Ladakh plateau and N. Kashmir Himalayas cold, Typic-arid eco-sub region). The region represents cold arid to cool humid (with inclusion of per humid) ecosystem (Velayutham *et al*. 1999). Due to high variability in relief the mean annual temperature ranges from 2 to 8 °C. The mean annual rainfall ranges from 100 to 115 mm in Leh/ Ladakh and 300-800 in rest of the regions.

Apart from pedogenic profile development, frigid and aridic properties of cold desert soils are needed to be considered at great group and subgroup levels for logical classification. Based on this consideration, the soils qualify for Cryic and Mesic soil temperature regime (MAST <8 °C; MSST <15 °C). Hence, Cryic subgroup is proposed by modifying the temperature classes. Thus there would be subgroup within the great group of Eutrochrepts *viz*., Cryic and Mollic; Cryic Eutrochrepts or Cryollic Eutrochrepts.

These soils cover an area of approximate 16.34 m ha. The Ladakh plateau is rugged mountainous terrain interspersed with narrow to nearly broad valleys. The elevated ranges remain under perpetual snow cover and the gently to moderately sloping and nearly level intermountain valleys have mostly skeletal soil cover with rockout crops. The soils of Ladakh region are generally skeletal with A-C profile due to effect of topography and frigid like aridic climate that restrict the chemical weathering, the soils are seldom subjected to leaching due to limited moisture supply (Sehgal *et al.* 1993). Yadav and Jagdish Prasad (2003) characterised the soils of Leh as Typic Eutrocryepts and that of Nubra valley as Typic Cryorthents. The moderately to gently sloping and nearly level intermountain valleys comprise the soilscape of Cryorthents and Cryorthids great groups (Sehgal *et al.* 1989; Walia *et al.* 1999). The soils in the area are in general shallow, mostly skeletal, coarse textured, calcareous and strongly alkaline soils (Sehgal *et al*. 1973). The soilscape of the lower reaches are represented by nearly level to very gently sloping Cryorthents and Cryorthids (Dhir 1967; Sehgal 1973; Walia *et al.* 1999). They are shallow, coarse textured calcareous soils, alkaline in reaction, low in organic matter. These soils are mostly light textured having low to medium organic carbon contents and variations are associated with altitude, land use and geology (Walia *et al.* 1999). The physiographic-wise distribution of soils across the states of J.K., H. P. and Uttarakhand are given in tables 1 and 2.

Land use

Because of severe climatic limitations, higher elevation and steep slopes, majority of area either remain barren or with thin and sparse vegetal cover of dry alpines scrubs. Excepts for a few patches of Himalayan meadow, Ladakh and Spiti are almost devoid of vegetation cover. Some stunted Cedars and Willows are found on moist strips. Dry alpine forest is mainly observed in Lahaul and upper part of Kinnaur areas. In valleys, deodar (*Cendrus libani*), Safedi (*Poplar* spp.) and willows (*Salix* spp.) are dominant trees. The dominant species in pastures are *Medicago sativa, M. falcate, Microule tibetica, Poa* spp.*, Lactuca* spp. *and Artemisia* spp. In other area,

sporadic vegetation of olium, wild roses and grasses are observed (HPKVV 1991). Nearly 5 to 10 per cent of geographical area is utilized as agricultural land for rainfed farming. The main crops grown are barley, wheat, buck wheat, pulses, peas, beans, kuth, potato and cabbage. All kinds of dry and temperate fruits, such as chilgoza, almonds, walnuts, chestnuts, resin, grapes, pistachio are grown. Some trees of medicinal importance and some horticultural crops like, cherry, strawberry, plum and apple are also grown in some areas.

Constraints

- Cryic temperature regime limits the choice of crops due to short growing period
- Rock outcrops
- Very steep slopes
- Excessive run-off and coarser texture of soils.
- Shallow, sandy and gravelly soils with shallow depth on steeply sloping hills.
- Low available water capacity (AWC)

Table 1. Soils of Greater Himalayas in different land forms

Soils of Greater Himalayas	Area M ha (% of TGA of the state)		
	J&K	Himachal Pradesh	Uttra-khand
Soils of summits, ridge tops , cliffs, valley glaciers Soils on very steeply sloping summits and ridge are shallow to deep, excessively drained, sandy-skeletal to loamy-skeletal with low AWC. They are slightly alkaline, highly calcareous, severely eroded and stony (Lithic Cryorthents and Typic Cryorthents). Soils of valley glaciers which are mostly snow covered or permanently under glaciers with considerable rock out crops are very shallow and sandy skeletal.	5.12 (23.0)	0.46 (8.2)	0.74 (13.8)
Soils of side/reposed slopes Soils on steeply to very steeply sloping denuded side/reposed slopes are shallow to medium, excessively drained, loamy-skeletal and coarse-loamy with low AWC. They are slightly alkaline, calcareous, severely eroded soils with moderate to strong stoniness (Lithic/Typic Cryorthents, Typic Udorthents). The soils on **steep hills with more than 40 per cent forests** are dominantly deep, well to excessively drained, coarse-loamy and loamy-skeletal with low to medium AWC. They are slightly acidic to neutral and moderately to severely eroded soils with moderate stoniness (Lithic/Typic Udorthents, Dystric Eutrochrepts). The soils on **bench terraces on steeply sloping hills** are mostly cultivated. They are medium deep to deep, well to excessively drained soils with wide ranges of particle size classes, *viz.* sandy-skeletal, loamy-skeletal, fragmental, coarse-loamy and fine-loamy. They are generally slightly alkaline, calcareous, having relatively high base saturation. The AWC is low to medium. The soils are classified as Typic Cryochrepts/Cryorthents in Cryic temperature regime and Typic Udorthents and Dystric Eutrochrepts in Mesic temperature regime.	10.4 (47.0)	2.01 (36.1)	0.83 (15.5)

Soils of Glacio-Fluvial valley			
Soils of gently to moderately steeply sloping glacio-fluvial valleys are occupied by medium deep to deep, well drained to excessively drained, loamy-skeletal and coarse-loamy to fine-loamy soils. These soils have low to medium AWC, dominantly slightly acidic to neutral with medium to high content of organic carbon. Some of the soils are highly calcareous and slightly to moderately alkaline and these soils are classified as Lithic/Typic Cryorthents, Typic Cryochrepts and Dystric Eutrochrepts.	0.01 (0.002)	0.12 (36.1)	0.03 (0.06)
Soils of Fluvial Valley			
Soils of gently to moderately sloping fluvial valleys are dominantly occupied by medium deep to deep, well to somewhat excessively drained, loamy-skeletal soils. They are mostly slightly acidic to neutral soils, with low AWC. They are classified as Typic Udorthents/Udifluvents and Dystric/Typic Eutrochrepts.	0.63 (3.0%)	0.03 (0.5%)	--

Soils of Greater and Lesser Himalayas (Mesic temperature regime mostly pertains to Kashmir valley. The characteristics of these soils are given in table 2. The important and extensive soils of Karewa landscapes are represented by Benchmark soils viz., Gogji Pather and Wahthora series (Murthy *et al*. 1982) occurring in parts of Anantnag district of Jammu and Kashmir state. Soils of Wahthora series (Murthy *et al*. 1982) occur extensively in broad valleys which remain snow covered for 2-3 months and remain waterlogged for longer duration in parts of Anantnag district and its surroundings. These soils are nearly neutral to mildly alkaline, deep, rich in organic matter and base saturated. Flood plain of Indus river system is mostly calcareous, neutral to slightly alkaline and represented by Udifluvents and Haplaquepts. These soils have good soil-air-water relationship. The plant available water capacity is high (180-200 mm m^{-1}). All climatically adaptable crops can be grown under rain fed condition.

Table 2. Soils of Greater and Lesser Himalayas (Mesic Temperature Regime)

Physiographic Region	Area M ha (% of TGA of the state)
Soils of side/reposed slopes	1.0 (4.5)
Soils on very steeply sloping summits and ridge are shallow to deep, somewhat excessively to excessively drained, mostly loamy-skeletal occasionally loamy and fine-loamy (patches) with low to medium and high AWC. They are slightly acidic, non-calcareous, high in organic carbon, severely eroded and moderate to severe stony soils (*Lithic/Typic Udorthents, Typic Dystrochrepts* and *Typic Hapludolls).*	
Soils of Fluvial Valley	
These soils further sub-divided in to broad and narrow valleys:	0.2 (1.0)
Soils of broad valleys are very deep, moderately well to imperfectly drained, mostly calcareous, fine-silty and fine-loamy, occurring on gentle slopes. They are mostly neutral to slightly	

alkaline, high in OC with medium AWC. These soils are prone to frequent flooding during rainy season due to overflow of river Jhelum. They are classified as *Typic Halaquepts, Typic Udorthents/Udifluvents* and *Dystric/Typic Eutrochrepts*.

Soils of narrow valleys are medium deep to deep, moderately well to well drained, mostly non-calcareous, and largely fine-loamy and coarse-loamy. They are slightly acidic in reaction, high in OC, with low AWC. They are moderately eroded (slight to moderate stoniness) and occasionally subjected to slight overflow.

Soils of Flood Plain 0.03 (0.1)

These areas are found to occur in Srinagar, Baramulla and Pulwama districts. They are situated at lowest elevation in the valley and are frequently inundated when Jhelum river swells up. The dominant soils are deep, imperfectly drained, calcareous, coarse-loamy developed on very gentle slopes. They are neutral to alkaline in reaction, high in OC and low to medium in AWC and are classified as *Typic Fluvaquents* and *Typic Haplaquepts.*

Soils of River Terraces 0.04 (0.2)

These soils are found in Kupwara, Baramulla, Badgaon, and Pulwama districts. These soils are dominantly deep, well to moderately well drained, fine-loamy to fine-silty, calcareous/non-calcareous and slightly eroded. They are rich in OC, mildly acidic to mildly alkaline and medium to high in AWC. These soils are classified as *Fluventic Eutrochrepts, Typic Eutrochrepts* and *Typic Udifluvents.*

Soils of Karewas 0.12 (0.53)

Karewas are flat-topped liked features in Kashmir valley and occur in Baramulla, Badgam and Pulwama districts and have developed on the morainic deposits of the Pliestocene glaciation. These are formed from clay, silt and sand of morainic origin. The soils are deep, well drained, fine-loamy and fine, calcareous/non-calcareous and slightly acidic to slightly alkaline with medium AWC and medium in OC. These soils are classified as *Fluventic Eutrochrepts, Typic Eutrochrepts, Dystric Eutrochrepts* and *Typic Hapludalfs.*

Soils of Piedmont Plain 0.2 (1.0)

Piedmont plains are further sub-divided into upper and lower piedmont plains. The soils of upper piedmont plains are deep, moderately well to well drained , fine-loamy to fine-silty or fine, calcareous/non-calcareous and slightly acidic to slightly alkaline with medium AWC and high in OC. These soils are classified as *Fluventic Eutrochrepts, Typic Eutrochrepts, Dystric Eutrochrepts* and *Aeric Halaquepts.*

The soils of lower piedmont are comparatively well developed than upper piedmont. They are classified as *Typic / Aquic Hapludalfs, Typic Eutrochrepts, Dystric Eutrochrepts* and *Typic / Aeric Haplaquepts.*

Land use: The soils on side/reposed slopes are mostly under forest and meadows but barren patches also exist. The soils of broad valleys are cultivated to paddy and at places for maize and plantation crops. The soils of low-lying areas are highly potential for rice followed by oil-seed crops. Well to moderately soils are suitable for up-land crops like maize, pulses, fodder crops and plantation (Rana *et al*. 2000). The soils of narrow valley are best suited to world famous rajmash crop. The soils of flood plains are suited for paddy cultivation. The soils of river terraces are cultivated to wheat, barley, maize, vegetables, oilseeds, pulses, *etc*. Soils of Karewas are cultivated to maize, saffron, and fruit crops like apple, almond, apricot, plum and pear (Staff NBSS&LUP 1992) as rainfed crops. The soils of piedmont plains are mostly under forests, fruit crops and partly cultivated to rice, vegetables and oilseeds.

Problems and potentials: Shallows depth, rock-outcrops, severe erosion, high run-off, steep to very steep slopes and low AWC of sandy and sandy-skeletal soils restrict the use of soils on side/ reposed slopes. The soils of valleys are subjected to floods during rainy seasons and play havoc to the crops as well as other infrastructure. The shallow water table, moderate to imperfect drainage, calcareousness, slow permeability due to heavy texture and compaction of sub-soils and crust formation are other major limitations for crop growth. The productivity of soils can be enhanced by adopting proper management practices such as rotational use of chemical fertilizers and irrigation water. Impeded drainage, flooding, and shallow water table are the major constraints which make flood plain soils unfit for growing agricultural crops except paddy and vegetables unless drainage is provided. Moderately drained soils, moderately shallow water table, moderately low to low permeability and crust formation are the main limitations of soils of river terraces. The productivity potential of these soils is medium to high which can be enhanced by adopting the appropriate agro-managements. Moderate erosion, gullies, droughtiness, low permeability due to fine-textured sub-soil, calcareousness and crust formation are the major limitations of Karewa soils. The productivity potential of these soils is high and a variety of climatically crops can be grown. The soils of piedmont plains are subjected to impeded drainage, moderate erosion, moderately slow to slow permeability.

Soils of Lesser Himalayas

These soils cover lesser Himalayas (valley of Kashmir and Pir Panjal ranges) in Punch, Rajouri, Udhampur, Doda and Kishtawar of Jammu region and all the districts of Kashmir region (1.4 M ha). In Himachal Pradesh, these soils cover Kinnaur, Shimla, Solan, Kullu, Mandi, Chamba and northern parts of Kangra and Sirmour districts (Sidhu *et al*. 2007a&b; HPKKV 1991). The total area under this unit is 1.75 M ha (31.5%). In Uttrakhand, these soils cover an area of 3.02 M ha which is 65.3 per cent of the TGA of state. This region experiences sub-tropical and temperate climate. The temperature and moisture regimes are thermic and udic, respectively.

Geology composed of granite and other crystalline rocks of unfossilifereous sediments. Slates and quartizites occur in the south-west flanks of Pir-Panjal.The length of growing period (LGP) is more than 150 days which is highly suitable for growing wide range of fruit and other crops. The area is deciduous and coniferous thick forests. The main crops grown are wheat, maize, barley and rice.

The soils of lesser Himalayas are highly variable depending on the vegetation and geology of the area and physiographic settings (Rana *et al.* 2000; Sidhu *et al.* 1997; Singh *et al.* 2004; Walia *et al.* 2010a,b,c; Karan Singh *et al*. 1993). The soils are shallow to deep, well to excessively drained, sandy, loamy-skeletal, coarse-loamy and fine-loamy, calcareous/ non-calcareous. The soils are slightly acidic to neutral on high reaches and neutral to slightly alkaline on lower hills. The organic carbon content of the soils is high to very high. These soils have been classified as Lithic/Typic Udorthents, Typic/Dystric Eutrochrepts, Typic Hapludolls and TypicUdifluvents (Kaistha and Gupta 1994; Sidhu *et al*. 1999). Typic Hapludalfs are also reported in lesser Himalayas of Kashmir Region (Kirmani *et al*. 2013).

The soils occurring on different landforms of lesser Himalayas, across the states of J&K, H.P. and Uttarakhand described below (Table 3).

Physiographic units	Area (M ha) (% of TGA of state)		
	H.P.	J&K	Uttra-khand
Soils of summits and ridge tops	0.04	0.56	0.50
Soils of moderately to very steeply sloping summits and ridge tops are shallow to medium, well to excessively drained, coarse-loamy and fine-loamy. The soils are neutral to slightly alkaline and severely eroded with low to medium AWC and are classified as *Typic Udorthents* and *Dystric Eutrochrepts.*	(0.07)	(0.25)	(1.67)
Soils of side/reposed slopes			
Soils occurring on moderately steep to very steep side/reposed slopes are highly variable depending on the vegetation and geology of the area. The soils are shallow to deep, well to excessively drained, sandy, loamy-skeletal, coarse-loamy and fine-loamy calcareous/non-calcareous. The soils are slightly acidic to neutral on high reaches and neutral to slightly alkaline on lower hills. The organic carbon content of the soils is high to very high. The soils have been classified as *Lithic/Typic Udorthents, Typic/Dystric Eutrochrepts* and *Typic Hapludolls.*	1.60 (28.9)	1.18 (5.3)	2.27 (7.72)
Soils of fluvial valleys			
The soils are medium deep to deep, well to excessively drained, stratified, coarse-loamy and fine-loamy mostly non-calcareous and neutral to slightly alkaline. The organic carbon status of these soils is moderate to high and AWC is moderate. The soils have been classified as *Typic Udifluvents, Typic Udorthents* and *Dystric Eutrochrepts.*	0.11 (1.9)	0.13 (0.57)	0.26 (0.87)

Land use: A major part of lesser Himalayas is under forests. The moist coniferous forests with an admixture of broad leaved trees are dominant species of the tract. This tract produces most of fruits especially in H.P. state. Intermittent sparse patchy terraced cultivation is also practiced on fairly steep slopes whereas dry and wet cultivation are prevalent on the uplands and low lying valleys respectively. The mail crops grown are *jhingora, madua*, wheat, maize, barley, rice, *etc*.

*Problems and potentials***:**

- The end of winter and beginning of summer rainy period coinciding with the thawing period, serve the rain fed agriculture of the area.
- Sub-optimum soil depth at escarpments and soil alkalinity at valley pose considerable limitations to the optimum uptake of moisture as well as nutrients.
- Low temperature commands the selective cropping in the area.
- Ground water development is difficult due to rocky terrain of the sub region.
- Horticultural crops, like apple, apricots and nuts can be grown under prevailing environmental condition.

Soils of Siwaliks (the outer Himalayas)

Soils of Siwalik regions covering an area of south-western part of Himalayas comprise Jammu region of J&K, Himachal Pradesh, Uttrakhand, Haryana, Uttar Pradesh and Punjab states (Fig.3). It includes the districts of Kangra, Hamirpur, Bilaspur, Una, Sirmour and southern parts of Solan and Chamba districts of H. P. state (1.1 M ha); Uttarkashi, Dehradun, Tehri Garhwal, Pauri Garhwal, Chamoli, Pithoragarh and Almora dis-

tricts of Uttrakhand. Northern wedge of Gurdaspur and Hoshirapur, Shahid Bhagat Singh Nagar and Rupnagar districts of Punjab, Jammu and Kathua districts of J&K state and Panchkula and Ambala districts of Haryana covered by Siwaliks. The Siwaliks predominantly consist of sedimentary rocks of Tertiary formations (extending from northwest to southeast) which comprise of sandstone and shales, clays and conglomerates (Gupta 1992). The climate is warm humid to per humid. This tract belongs to AESR 14.1 and 14.2 (South Kashmir and Kumaon Himalayas, warm, moist dry sub humid eco-sub region). The mean annual rainfall ranges from 600 to 1300 mm and mean annual temperature varies between 12 to 14 ^{o}C.The area is highly prone to water erosion during the monsoon. LGP ranges from 210-300 days.

The soils of Siwaliks are extensively studied by various workers (Gupta and Verma 1992; Rao *et al.* 1993; Sidhu *et al*. 1998, 2000, 2008; Sidhu and Jain 1993). The denuded hills have thin forests pertaining to tropical dry deciduous and tropical thorny forests. The soils of this region comprise brown forest and podzolic soils. The moderately to gently sloping topography have Hapludalfs, Hapludolls, Eutrochrepts whereas moderately to steeply sloping pediments at lower elevations are represented by Udorthents, Haplumbrepts, Argudolls. The nearly level to level flood plain of Indus river system are mostly calcareous, neutral to slightly alkaline and represent Udifluvents and Haplaquepts (Sidhu *et al*. 1987). The dominant soil great group associations covering the area are Ustochrept - Udorthents, Ustochrept - Udorthents - Haplustalfs, Hapludalfs - Entrochrept and Hapludolls in association with glacier. The other great group associations found in pockets are Ustochrepts - Ustorthents and Hapludalfs - Ustochrepts - Ustochrepts - Ustorthents, Ustorthents- Ustorthents with gullied land (Sehgal *et al.* 1993)

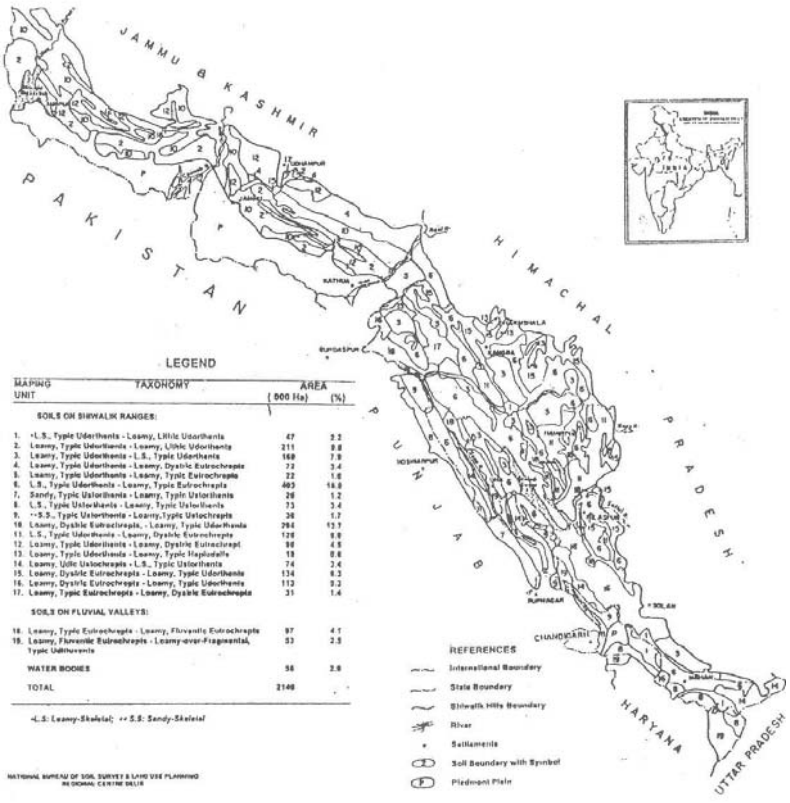

Fig. 4. Soils of Siwaliks of north-western Himalayas

Table 4. Soils of Siwaliks

Soils of Siwaliks	Area M ha (% TGA of the state)					
	H.P.	J&K	Uttra-khand	Har-yana	Punjab	U.P.
Soils of summits and ridge tops	0.03		0.05	-	-	
The moderately steep to steeply sloping hills of H.P. have medium deep to deep, well to excessively drained, loamy-skeletal, severe to very severely eroded soils. The soils are slightly acidic to slightly alkaline with moderate to high organic carbon and low AWC (Lithic/Typic Udorthents)	(0.4)		(0.17)			
Soils of side/reposed slopes						
The soils are medium deep to deep, well to excessively drained, loamy-skeletal, coarse- loamy and fine-loamy with moderate to severe erosion. They are slightly acidic to slightly alkaline (in some cases moderately alkaline) soils with low to moderate AWC. These soils are classified as Lithic/Typic Udorthents and Typic/Dystric Eutrochrepts. The soils around Palampur area are classified as Typic Hapludalfs and support tea gardens.	0.97 (17.6)		0.29 (0.98)	0.06 (1.4)	0.02 (2.9)	-
Soils of fluvial valleys						
Soils occurring on very gentle to moderately sloping fluvial valleys are mostly medium deep to deep, well drained, sandy, sandy-skeletal, coarse-loamy and fine-loamy with moderate erosion. The soils are neutral to moderately alkaline with low to medium organic carbon and low to medium AWC. The soils have been classified as Typic Ustifluvents, Udic Ustochrepts and Typic Ustorthents.	0.08 (1.5)		0.12 (0.40)	-	-	-
Soils of piedmont plains						
Soils occurring on very gently to gently sloping piedmont plains are medium deep to deep, well drained, coarse-loamy with moderate to severe erosion. The calcareous/non-calcareous soils are slightly to moderately alkaline with low to medium organic carbon and medium AWC. The soils have been classified as Udic Ustochrepts and Typic Ustorthents.	0.07 (1.2)	-	-	0.07 (1.6)	0.35 (6.9)	0.72 (2.44)

mixed, Mesic family of Mollic Haplaquepts. These soils are developed in alluvium of intermountain valleys. The clay content increases with depth whereas the surface horizon is rich in organic carbon. These are highly base saturated and agriculturally important soils under rain fed condition.

Very deep, fine-loamy, slightly acidic to neutral and moderately eroded soils occurs on Siwaliks and they are classified as Dystric Eutrochrepts (Sidhu *et al.* 1999; Sudhakar Rao *et al.* 1997) and Typic Udorthents/Typic Dystrochrepts (Gupta and Chera 1996). The details of soils are presented in Table 4.

Land use: The natural vegetation is of diverse nature comprising scrub forests, pine forests, fir, spruce, birch, rhodendrons and alpine vegetation with the common species of *Acacia nilotica*, *Acacia catechu*, *Dalbergia* sissoo, *Pinus excels*, *Pinus roxburghi*, *Cendrus deodara*, Bauquercus, *Abbis webbiana*, *etc*. Agriculture is dominantly practiced in the valleys and on terraces of lower and middle hills. The sub-region has rice (Oryza sativa)/ maize (*Zea mays*) based cropping system. The common crop sequence followed in Jammu & Kashmir part is rice-wheat, and at places paddy/maize-potato-wheat (*Triticum aestivum*) or rice-wheat-mungbean. Gram lentil and mustard and oil seeds are also grown. In Himachal Pradesh (part of the sub-region), maize and rice are the important kharif crops whereas wheat and barley are rabi crops. These sub-regions is famous for tropical and temperate food production. Apple is dominating temperate fruit crop of this region. Other temperate fruits like peach, plum, apricot, pears, and walnut are widely grown. This zone produces large number of summer vegetables like cauliflower, cabbage, reddish, capsicum and potato at lower terraces. The common crops grown are millet, maize and rice. The terraced uplands are cultivated for paddy and/or horticultural plantation crops, like apples, apricot, resin grapes are important. The important cultivated fodder crop in the region is alfalfa for supporting large cattle population. Maize/rice-wheat based cropping is followed in the sub region; the productivity of all the crops is low.

*Problems and potentials***:**

- Severe to very severe erosion on steep to very steep hills.
- Shallow depth in some soils Deforestation on high slopes, favoring soil erosion.
- Soil degradation, resulting from landslides during heavy rain or snow.
- Imperfect drainage conditions in valleys, limiting the choice of crop to paddy.
- Droughtiness, especially in the lower hills, due to excessive relief and coarser soil texture.
- Low AWC and nutrient retention capacity of some soils.
- Moderate to severe stoniness

Soil degradation in north-western Himalayas and its management

Himalayan system is very fragile system due to steep landscape. Soil degradation in Himalayas is the major concern for sustainable agriculture, forests, maintaining eco-friendly environment and livelihood for the people. Soil erosion is the main cause for soil and land degradation. The exposed land gets eroded by rains causing floods in the rivers and sedimentation in reservoirs. This has created the problem of siltation in the dams thereby reducing their capacity as well as age (Table 5). The data show wide variation in sedimentation depending upon the topographic position, soils and vegetation. Therefore, soil erosion is very important even in assessing the existence of infrastructure like dams.

Table 5. Sediment data of selected reservoirs

Reservoirs	Year of Impounding	Annual rate of silting in ha m/100sq.km.	
		Assumed	Observed
Bhakra	1959	4.29	6.10
Beas unit II	1974	4.29	14.30
Panchet	1956	2.41	10..00

Source: Dewan and Sharma (1985).

The soil erosion data in some of the states (Table 6) shows the severity of soil erosion classes. The soil degradation in different landforms of the states is discussed below:

Table 6. Status of soil erosion in different states of India

State	*Soil loss through water erosion (Area M ha)				*Soil erosion through wind				Reference
	1	2	3	4	5	6	7	8	
Himachal Pradesh	1.6	0.3	0.6	0..9	-	-	-	-	Sidhu *et al.* (2010)
Uttarakhand	0.8	0.4	0.8	3.3	-	-	-	-	Jagat Ram *et al.* 2013
Punjab	4.7	1.1	1.3	0.7	-	-	-	-	Sidhu *et al.* (2013)
Haryana	3.2	0.07	0.05	0.4	0.9	0.05	0.09	0.002	Sachdev *et al.* (2011)

*1, 5-Slight (<10 t ha^{-1}); 2, 6-Moderate (10-15 t ha^{-1}) ; 3, 7-Severe 15-40 t ha^{-1}); 810 4, 8-Very severe 40-8- t ha^{-1})

Greater and Lesser Himalayas

Since sloppy landscape is the main cause of land degradation, proper engineering measures as well as soil and water conservation practices should be adopted to arrest further degradation of soils. Land up to 33 per cent slopes may be cultivated for agricultural crops following suitable agro-practices. Sloping lands can be benched as terraces and may be improved by providing shoulder bunds, leveling and inter-terrace drains. Agricultural crops should be raised using good agronomic practices like contour farming, mulching, intercropping with legumes, high yielding improved seeds, fertilizers, manures, pesticides, etc. and also on watershed management basis for harnessing the water resources (Suri *et al*. 2013). Landforms with slopes from 33-50 per cent may be brought under suitable horticultural plantation and orchards after constructing proper engineering structures, land-shaping, such as orchard terraces may be resorted to. Land with slopes more than 50 per cent should be brought under permanent vegetation of suitable fuel, fodder, tree species and grasslands with soil conservation measures like contour trenching, staggered trenching and contour furrows (Singh *et al.* 1990). The area of shallow soil which is not suitable for tree may be treated with engineering measures like gully plugs, check dams, spurs, etc. and rehabilitated by proper vegetative measures. Partial development with improved seeds may be taken up in areas where no agricultural practices are possible.

Siwaliks

As far as the north western Siwaliks are concerned, about 36 per cent area is affected by severe soil erosion, 49 per cent by moderate and 13 per cent by slight erosion (Sidhu *et al*. 2009, 2010; Yadav and Sidhu 2010). Stoniness covering 25 per cent area is also a major problem in severely eroded areas. These areas should be treated by adopting suitable soil conservation measures to minimize soil erosion losses. These soils need intensive soil conservation measures along with introduction of erosion resistant varieties of grasses like *Bhabbar grass* which can also be utilized for paper manufacturing. Some of these soils are well suited for raising horticultural crops, protected pastures, forestry and recreational activities. Soil degradation status of Himachal Pradesh has been shown in table 7 (Sidhu *et al*. 1997).

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Table 7. Soil degradation (M ha) status of Himachal Pradesh

Nature of soil degradation	Degree of degradation (%)				Total area	
	Slight	Moderate	Strong	Extreme	(M ha)	(%)
Water erosion	0.11 (2.0)	0.88 (15.9)	1.87 (33.5)	0.13 (2.4)	2.99	53.8
Stoniness	0.16 (2.9)	0.91 (16.3)	0.22 (3.9)	-	1.29	23.1
Flooding	-	0.02 (0.3)	-	-	0.02	0.3
Land not fit for agriculture (Rocky outcrops, glaciers)	-	-	-	-	1.27	22.8
Total	0.27 (4.9)	1.81 (32.5)	2.09 (37.4)	0.13 (2.4)	5.57	100

Source: Sidhu *et al*. (2007). Figures within parentheses shows % of total geographical area.

Soil health management options in Himalayas region

Limited availability of additional land for crop production, along with declining yield growth of major food crops, have heightened concerns about agriculture's ability to feed increasing population in the hill region where only 10-15 per cent land is available for cultivation. Soil degradation leads to hamper the soil fertility which is great concerns about the sustainability of agricultural production at current levels. Future strategies for increasing agricultural productivity will have to focus on management of natural resources, using available nutrient resources more efficiently, effectively, and sustainably than in the past. Integrated management of the nutrients needed for proper plant growth, together with effective crop, water, soil, and land management, will be critical for sustaining agriculture over the long term. Integrated nutrient management (INM) is an approach that seeks to both increase agricultural production and safeguard the environment for future generations. It is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation, and thereby help meet future food supply needs. It relies on nutrient application and conservation, new technologies to increase nutrient availability to plants, and the dissemination of knowledge between farmers and researchers. The success of INM will depend upon the combined efforts of farmers, researchers, extension agents, governments, and non-governmental organizations (NGOs).

Suri *et al.* (2013) outlined the major soil management options for improving soil health in western Himalayas. The land capability classification of the hilly state like H.P. is needed for proper management of natural resources especially on steeply sloping areas (Karan Singh *et al*. 1992). Achieving balance between the nutrient requirements of plants and the nutrient reserves in soils is essential for maintaining high yields and soil fertility, preventing environmental contamination and degradation, and sustaining agricultural production over the long term. The soils of Himalayan region are, generally, deficient in nutrients like nitrogen, phosphorus, calcium, magnesium, sulphur, zinc, boron, molybdenum and iodine (Gupta *et al*. 1985). These need to be supplied by addition of inorganic and organic fertilizers to maintain a steady supply of essential nutrients to crops. The fertilizer use (N, P and K) is still below the national average of 104 kg ha^{-1} in Himalayan states; the figures being 84, 50, 92 and 50 kg^{-1} for Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Assam, respectively (Fertilizer Statistics, 2005-2006). Besides inadequate use, the fertilizer use is highly imbalanced with the addition of urea alone supplying only single nutrient nitrogen. The inadequate and imbalanced fertilizer use coupled with no addition of organic manures has led to the emergence of multi-nutrient deficiencies in many areas. The effect of climate and land use on soil organic stock and soil organic density was studied by Singh *et al*. (2011 & 2013) under variable soil moisture and temperature conditions in arable and non-arable lands. The land use, soil, moisture and temperature regimes have significantly influenced the soil carbon stock and density.

Strategies for the development of the region

- ☞ Manmade ecological degradation should be reversed especially in the lower foot hills through land development activities such as land shaping, terracing, bunding and re-vegetation, *etc*.
- ☞ Rehabilitation of higher hills through reduction of run-off and erosion especially in shallow, sandy and skeletal soil on steep slopes. It can be done by adopting suitable soils conservation measures and afforestation/ re-vegetation.
- ☞ Investigation and research on surface hydrology, groundwater, micro watershed development, etc. should be strengthened.
- ☞ Integrated watershed development to further reduce soil degradation, run-off, erosion and water scarcity should be practiced.
- ☞ Monitoring the effect of climate change on soils, soil carbon, and length of growing season.

References

Biswas, T.D. and Mikherjee, S.K. (1994). Text book of Soil Science, 2nd Ed. Tata MC Graw, Hill Publ. Co. Ltd., New Delhi p.365.

Biswas, T.D. and Mukherjee, S.K. (1994). Text book of Soil Science, 2nd Ed. Tata MC Graw Hill Publ. Co. Ltd., New Delhi p.365.

Dewan, M.L. and Sharma, Sudhirendar (1985). People's participation as a key to – Himalayan Eco-system Development. *Report of the NGOs Meeting at the Centre for Policy Research,* Published by Centre for Policy Research Dharma Marg, Chanakyapuri, New Delhi. pp. 56.

Dhir, R.P. (1967). Pedological characteristics of some soils of the NW Himalayas. *Journal of the Indian Society of Soil Science* **15**, 61-69.

Gawande, S.P., Sharma, S.P. and Chavan, R.K. (1979). Soils of command area of Abichemethong canal in Ladakh and their management needs. *Journal of the Indian Society of Soil Science* **27**, 427-433.

Gupta, R.D., Marwaha, B.C., and Bali, S.V. (1985). Soils of Jammu and Kashmir and their management. In 'Soils of India and their management'. (Fertilizer Association of India, New Delhi).

Gupta, R. D. and Verma, S.D. (1992). Characterization and classification of some soils of Kandi Belt in Jammu Siwalik Hills. *Journal of the Indian Society of Soil Science* **42,** 809-815**.**

Gupta, Sanjay and Chera, R.S. (1996) Soil characteristics as influenced by slope aspects in Middle Siwaliks. *Agropedology* **6,** 43-48.

HPKKV (1991). *Status Report on Kinnaur and Spiti Catchment of Sutlej River in* Himachal *Pradesh,* HPKVV, Palampur.

Jagat Ram, Singh, S.P., Yadav, R.C., Mahapatra, S.K., Sidhu, G.S., Sarkar, Dipak, Singh, S.K., Sharda, V.N. (2013). Soil erosion in Uttrakhand, NBSS Publ. 156, NBSS&LUP, Nagpur, India, pp53.

Kaistha, B.P., and Gupta, R.D. (1994). Morphology and characteristics of few Entisols and Inceptisols of North-western Himalayan Region. *Journal of the Indian Society of Soil Science.* **42,** 100-104**.**

Karan Singh, Sharma, P.D. and Bhandari, A.R. (1992). Land capability classes and management needs for sustained productivity in semi-arid regions of north-west Himalayas, *Agropedology* **2,** 51-57.

Karan Singh, Tripathi, D. and Tomar, K. P. (1993). Pedogenesis and taxonomy of soils in topo-sequence of Central Himalayas. *Agropedology* **3**, 29-38.

Kirmani, N.A., Wani, Mushtaq, A. and Sofi, J.A. (2013). Characterization and classification of Alfisols under lesser Himalayan temperate region. *Agropedology* **23,** 118-121.

Mahapatra, S.K., Rana, K.P.C., Sidhu, G.S. and Walia, C.S. (2000a). Assessment of soil degradation status of Jammu and Kashmir state for their amelioration. *Journal of the Indian Society of Soil Science* **48**, 577-80.

Mahapatra, S.K., Rana, K.P.C., Sidhu, G.S., Walia, C.S. and Tarsem Lal (2000b). Characterization and classification of the soils of different physiographic units in the sub-humid eco-system of Kashmir region. *Journal of the Indian Society of Soil Science* **483,** 572-76.

Murthy, R.S., Hirekerur, L.R., Deshpande, S.B., Venkta Rao, B. eds. (1982). Benchmark soils of India, NBSS&LUP, Nagpur, 379p.

Rana, K.P.C., Walia, C.S., Sidhu, G.S., Singh, S.P., Velayutham, M. and Sehgal, J. (2000). Soils of Jammu & Kashmir for optimizing land use. NBSS Publ. 62.

Rao Sudhakar, R.V., Mahapatra, S.K., Verma T.P., Sidhu, G.S. and Rana, K.P.C. (1997). Characterization and classification of some soils of Siwaliks hills in Himachal Pradesh. *Agropedology* **7,** 14-21.

Sachdev, C.B., Tarsem Lal, Rana, K.P.C. and Sehgal, J. (1995). Soils of Haryana for Optimizing Land Use NBSS Publ. 44 (Soils of India Series). National Bureau of Soil Survey & Land Use Planning, Nagpur, India, 59 p + 2 sheets soil map (1:50,000 scale).

Sachdev, C.B., Yadav, R.P., Sidhu, G.S., Sharma, J.P., Singh, S.P., Tiwari, A.K., Aggarwal, R.K., Sarkar, Dipak and Sharda, V.N. (2011). Soil erosion in Haryana, Technical Bulletin No. 149, NBSS & LUP, Nagpur, India, pp34.

Saharan, Neelam, Rattan, R.K., Sidhu, G.S. and Rana K.P.C. (2001). Sulphur fertility status of the soils of Himachal Pradesh. *Fertiliser News* **46,** 49-53.

Sawhney, J.S., Verma V.K. and Jassal, H.S. (2000). Soil physiographic relationship in southern sector of sub-mountain tract of Punjab. *Agropedology* **10,** 6-15

Sehgal, J.L. (1973). Studies of some soils in NW Himalayas and the highlands of India. *Geoderma* **9**, 59-74

Sehgal, J., Singh Karan, Jagat Ram, Sidhu, G.S and Gajbhiye, K.S. (1993). Cold desert soils of India –Their taxonomic problems. *Agropedology* **3,** 13-28.

Sehgal, J., Singh, K., Sidhu, G.S. and Gajbhiye, K.S. (1989). Soils of cold desert areas in India and their Taxonomic Problems. VI Intl., Soil Correlation Meeting. August, 5-18, 1989, Canada & USA, p.10.

Sehgal, J.L., Sys, C., Stoops, G. and Tavernier, R. (1985). Morphology, genesis and classification of two dominant soils of warm temperature and humid region of the central Himalayas. *Journal of the Indian Society of Soil Science* **33,** 846-57.

Sen, T.K. Nayak, D.C., Singh, R.S., Dubey, P.N., Maji, A.K., Chamuah, G.S., and Sehgal, J. (1997). Pedology and edaphology of Benchmark acid soils of north eastern India. *Journal of the Indian Society of Soil Science* **45**, 782-790.

Sidhu, G.S. and Jain, S.P. (1993). Soil survey and evaluation of ORP villages Boothgarh, Jhandupur & Majhot, district Hoshiarpur, Punjab. Report No. RCD 91 NBSS&LUP Publ.

Sidhu, G.S., Pal Sharmistha, Tiwari, A.K., Sarkar, Dipak and Sharda, V.N. (2013). Soil erosion in Punjab, NBSS Publ. No. 151, NBSS & LUP, Nagpur, India, pp.33.

Sidhu, G.S. and Rana, K.P.C. (2010). Utilization of soil survey data for watershed development in hilly areas - A case study In Resource management in developing countries Vol. V - Soil deterioration and conservation, Thakur B., (Ed),. Concepts' International Series in Geography, New Delhi.

Sidhu, G.S., Rana, K.P.C., Rao, R.V.S., Mahapatra, S.K., Verma, T.P., Lal, Tarsem, Ram, Jagat and Singh, S.K. (1998). Soils of Himachal Pradesh: Their interpretation for thematic mapping and land use planning. Presented and abstracted in "International Symposium on Sustainable Agriculture in Hilly Areas," held at HPKV, Palampur on October 29-31, HPKKV, Palampur, India.

Sidhu, G.S., Rana, K.P.C., Sehgal, J., and Velayutham, M. (1997). Soils of Himachal Pradesh for optimizing land use. NBSS publ. 57. (Soils of India Series). National Bureau of Soil Survey & Land Use Planning, Nagpur, India, 44 p + 2 sheets soil map (1:50,000 scale).

Sidhu, G.S., Rana, K.P.C., Walia, C.S., Mahapatra, S.K. and Tarsem Lal (1998). Characteristics and classification of dominant soils of Jammu region for land use planning. *Agropedology* **9**, 22-29.

Sidhu, G.S., Rana, K.P.C. and Tarsem Lal (1987). Soil survey and land evaluation of sub-watershed area " Meer-Noara" Udhampur district, J&K. National Bureau of soil survey and land use planning. Scientific Report No. 490 (ICAR), Nagpur.

Sidhu, G.S., Rana, K.P.C., Tarsem Lal, Mahapatra, S.K., Verma, T.P., Rao, R.V.S., Jagat Ram, Singh, S.K. and Singh, S.P. (2007a). Soils of Himachal Pradesh: Inventory for land use planning. *Journal of the Indian Society of Soil Science* **55**, 203-208.

Sidhu, G.S., Rana, K.P.C., Tarsem Lal, Mahapatra, S.K., Verma, T.P. and Rao, R.V.S. (2007b). Soils of Himachal Pradesh – II: Land capability classification and assessment of soil degradation status for suggested land use. *Journal of the Indian Society of Soil Science* **55**, 335-339.

Sidhu, G.S. and Sharma, J.P. (2008). Soil resource data for perspective land use planning in Shiwaliks of Himachal Pradesh. In "*State Level Workshop on Catchments Treatment of River Valley and Flood Prone Areas in Himachal Pradesh*," Dr Y. S. P U H & F, Nauni (Solan), NRM Div. of Min. of Agric. and H. P. State Department of Forests.(ISBN 978-81-211-0676-4).

Sidhu, G.S., Yadav, R.P. and Sharma, J.P. (2009). Soil Erosion Status in Himachal Pradesh for Land Use Planning. In *Conservation Farming, Post Publication of 2nd International Conference* (Eds. Suraj Bhan, R. L. Karale, Shamsher Singh,V. K. Bharti and J.S. Bali) Soil Conservation Society of India, New Delhi.

Sidhu, G.S., Yadav, R.P., Singh, S.P., Sharma, J.P., Aggarwal, R.K., Tiwari, A.K., Gajbhiye K.S., Sarkar, Dipak and Sharda, V.N. (2010). Soil erosion in Himachal Pradesh, NBSS Publ. No. 132, NBSS & LUP, Nagpur, India, pp. 53.

Sidhu, G.S., Walia, C.S., Rana, K.P.C. and Sehgal, J. (1995). Soils of Punjab for optimizing land use. NBSS publ. 45 (Soils of India Series). National Bureau of Soil Survey & Land Use Planning, Nagpur, India, 75 p + 2 sheets soil map (1:50,000 scale).

Sidhu, G.S., Walia, C.S., Sachdev, C.B., Rana, K.P.C., Dhankar, R.P., Singh, S.P., and Velayutham, M. (2000). Soil Resource of N-W Shiwaliks for Perspective Land Use Planning. In *Fifty Years of Research on Sustainable Resource Management in Shivaliks* by S.P. Mittal, R.K. Aggarwal and J.S. Samra (*Eds*.). CSWCRTI, Research Centre Chandigarh – 160019 (India).

Singh G., Venkataramanan C., Sastry G., Joshi B.P. (1990). Manual of soil and water conservation practices, Oxford, IBH Publishing Company, Pvt. Ltd., New Delhi.

Singh, S.K., Pandey, C.B., Sidhu G.S., Sarkar Dipak and Sagar R. (2011). Concentration and stock of carbon in the soils affected by land uses and climates in the Western Himalaya, India. *Catena* **87,** 78-89.

Singh, S.K., Sidhu, G.S., Choudhury Gupta, Shreyasi, Pandey, C.B., Banerjee, Tapati and Sarkar, Dipak. (2013). Soil Organic Carbon Density in Arable and Non-arable Lands under Varied Soil Moisture and Temperature Regimes in Cold Arid to Sub-tropical Areas of Western Himalaya, India. *Arid Land Research and Management* **28,** 169-185.

Singh, S.P. Jagat Ram, Walia, C.S., Sachdev, C.B., Dhankar, R. P., Rana, K.P.C., Sehgal, J., Velayutham, M. and Gajbhiye, K.S. (2004). Soils of Uttar Pradesh for optimizing land use. NBSS Publ. 68.

Staff NBSS&LUP (1992). The Soils of Anantnag and part Pulwama district (Jammu & Kashmir) for Land Use Planning**,** Report No. 26**,** NBSS&LUP, Nagpur Publ.

Staff NBSS&LUP (1998). Soils of Bilaspur district (Himachal Pradesh) for Land Use Planning, Report No.536 (ICAR) NBSS&LUP Publ.

Suri, V.K., Sidhu G.S. and Kumar Anil (2013) Physical attributes: Soil and landscape characteristics of western Himalayan region of India *In:* Climate Change and its Ecological Implications for the Western Himalaya (Ed. Chopra VL), Scientific Publishers, Jodhpur. (ISBN : 9788172338091), pp.1-48.

Tarsem, Lal**,** Sidhu, G.S., Surya, Jaya N., Kamble, H. Kalpana and Sharma, J.P. (2006). Assessment of natural resources for suitability of rice cultivation in lesser Himalayas and Shiwaliks- A case study of Solan district, Himachal Pradesh, India. Presented and abstracted in Proceedings of *2nd International Rice Conference,* held at New Delhi on October 9-13, 2006. 2nd International Rice Conference, New Delhi, India.

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J. (1999). Agro-ecological subregions of India for development and planning. NBSS & LUP Publ. 35, NBSS & LUP, Nagpur, India, 452p.

Verma, T.P., Mahapatra, S.K., Rao, R.V.S., Lal, Tarsem,Sidhu, G.S. and Rana, K.P.C. (1999). Changes in soil characteristics in relation to physiography and land use in higher Himalayan region of Himachal Pradesh. *Indian Journal of Soil Conservation* **43,** 189- 196.

Yadav, R.P. and Sidhu, G.S. **(**2010). Assessment of soil erosion in Himachal Pradesh. *Journal of the Indian Society of Soil Science* **58**, 212-220

Walia, C.S., Surya**,** Jaya N., Dhankar, R.P., Harjit Singh, Goyal Vishal, Khajuria Vishal and Sharma, J.P. (2010b). Evaluation of soil resource data of Kulgad watershed for land use planning. Abstract published in the proceedings of 75th Annual convention of the Indian Society of Soil Science held at Bhopal, p.58-59.

Walia, C.S., Jaya N. Surya, Dhankar, R.P., Sharma, J.P. and Dipak Sarkar (2010c). Generation of Soil Database for Kulgad Watershed Development in Almora District, UttrakhandUnder DST Coordinated Research Program on "Bio-Geo Database and Ecological Modeling for the Himalayas (BIO-Geo DEM) NBSS Tech. Bull. No.1043.

Walia, C.S., Rana, K.P.C. Sidhu, G.S., Mahapatra, S.K. and Tarsem Lal (1999). Characterization and classification of some soils of Ladakh region for land use. *Agropedology* **9**, 16-21.

Walia, C.S. , Surya, Jaya N., Dhankar, R.P. , Sharma, J.P., Harjit Singh, , Khajuria, Vishal and Goyal, Vishal (2010a). Soil resource characterization in Kumaon Hills using remote sensing and GIS for land use planning. Abstract published in the proceedings of National Seminar on Issues of Land Resource Management: Land Degradation, Climate Change and Land Use Diversification, held at Nagpur, pp.107.

Yadav, Janardan and Jagdish Prasad (2005). Characteristics of some typical pedons from Leh. *Annals of Arid Zone* **44**, 195-198.