Catena 81 (2010) 203–208

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

# Landscape and land use effects on soil resources in a Himalayan watershed

Debashis Mandal *, Ratan Singh, S.K. Dhyani, B.L. Dhyani

*Central Soil and Water Conservation Research and Training Institute, 218 Kaulagarh Road, Dehradun, India*

ARTICLE INFO

*Article history:*
Received 30 March 2009
Received in revised form 13 March 2010
Accepted 17 March 2010

*Keywords:*
Soil functionality
Erosion resistance
Landscape and land use
Organic matter supply and nutrient cycling

ABSTRACT

Sustainable land management decisions at all scales require solid, science-based information. Soil quality assessment can provide this regarding soil physical, chemical, and biological characteristics and the ability to provide ecosystem and societal services. Our objective was to make a regional assessment of soils in the Garhwal Himalayas to determine their ability to perform various functions and respond to external influences. Five functional categories were assessed using 13 soil parameters focused on ecological sustainability. Human land use effects on soils were referenced to natural woodlands at each landscape position. Within upper-slope regions, flora and fauna habitat, moisture retention, organic matter and nutrient cycling, air and water infiltration and resistance to erosion were decreased 35, 27, 24, 24, and 9%, respectively. At mid-slope positions the order and magnitude of decrease were organic matter and nutrient cycling, flora and fauna habitat, and moisture retention (26, 22, and 16%, respectively). Changes within the valley were lowest, averaging −3% for flora and fauna habitat and −13% for organic matter and nutrient cycling. We conclude that the minimum data set (MDS) used provided a representative assessment of soil quality and could serve as a basis for assessment in similar tropical watersheds.



## 1. Introduction

Environmental degradation due to poor land use decisions is a worldwide problem that threatens sustainability (Pierce and Larson, 1993; Zinck and Frashad, 1995; Hurni, 1997; Hebel, 1998) and has caused severe soil quality degradation in the tropics (Lal, 1990). Principal causes of degradation in mountainous ecosystems are soil erosion and water deficits (Torrent, 1995; Hill et al., 1996; De la Rosa et al., 1999; Sharma, 2004; Saxena et al., 2005). For example, in the Garhwal Himalayan region, most soils are classified as Entisols with many being degraded due to water erosion. Recent studies (NBSSLUP, 2004; Sharma, 2004) have shown that 72% of this geographical area has suffered severe water erosion at rates often exceeding 20 Mg $ha^{-1}$ $yr^{-1}$.

Land use profoundly influences soil functions at multiple levels within agro-ecosystems. In many areas, human pressure for production has modified land use and is causing unknown ecological effects (Sharma, 2004). When adversely affected, the soil is often dysfunctional in many respects. Ecological sustainability requires that several functions be maintained (De Kimpe and Warkentin, 1998; Shaxson, 1998). This includes: water flow and retention, solute transport and retention, physical stability and support, retention and cycling of nutrients, buffering and filtering of potentially toxic materials, and maintenance of biodiversity and habitat (Daily et al., 1997).

In the Himalayan region, agricultural production has direct linkage to surrounding ecosystems. Therefore, even though the most important concerns are to protect soil productivity and sustain production, an equilibrium should be maintained between agricultural production and surrounding natural ecosystems (Lefroy et al., 2000; Saxena et al., 2005). Failing to stop the continued degradation of the fragile Himalayan region would adversely affect socio-economic and environmental stability not only in the highlands, but also in the lowlands (Sharma, 2004).

To improve land use decisions, information is needed to understand effects of various management practices at multiple scales. Doing so by integrating appropriate factors within a landscape would provide a better recognition of the quality and management of entire agro-ecosystems (Kessel and Wendroth, 2001). One way to accomplish this is to use soil quality indicators that correlate well with ecosystem processes. These indicators should also integrate soil properties and processes, be accessible to many user, sensitive to management and climate, and wherever possible, be components of existing databases.

The direction and degree of soil quality change in managed mountain ecosystems depend on climate, soil conditions, and land use. The majority of previous studies (e.g. Wang and Gong, 1998; Perie and Munson, 2000; Islam and Weil, 2000) have focused on individual aspects of soil quality such as biological productivity, water cycling, or environmental quality. Many have also occurred in temperate regions with few studies undertaken in the sub-tropics and tropics. To reverse degradation processes in the sub-tropics and tropics, assessments of soil functions are urgently needed (Stocking, 2003). Our objectives were to (i) numerically assess soil quality using a systematic framework and

* Corresponding author.
*E-mail address:* demichael@rediffmail.com (D. Mandal).

0341-8162/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.catena.2010.03.004

(ii) evaluate different land use and management impacts on soil function and quality indices. Accomplishing these was envisioned as a guide for planning sustainable land use and management practices in other tropical areas.

## 2. Materials and methods

### 2.1. Background

The study was conducted at 30° 15′ N latitude and 78° 30′ E longitude in a hill and mountainous watershed in Garhwal Himalayas, India. The investigation was designed to compare soil characteristics within agricultural areas with those in comparable forest reference sites. The catchment occupies about 348 ha with elevation from 780 m to1680 masl (meters above sea level). Topography is highly variable and steep in the upper and mid-slope areas to flat in the broad valley areas. The climate is sub-tropical and the rainfall distribution is marked by a dry season from October to May and a wet season from June to September. The annual rainfall ranges from 589 mm to 1215 mm with an average of 856 mm. The reliefs are dynamic in the landforms and are subject to continual slumping, erosion and redistribution of sediments. The important rock formations are phyllite, schists and gneiss. The soils on the catchments are classified as Typic Udorthents, Typic Ustorthents and Dystrustepts (Soil Survey Staff, 1998). The soils in upper reaches are light-textured and shallow. The valley soils are deep with high clay content (17.2%) on paddy terraces and sandy loam to loam along the torrents. Soil pH is towards neutral (varies from 6.2 to 7.6) with medium to high organic carbon (0.70–2.39%), medium in extractable P (14.0–30.8 kg $ha^{-1}$), and medium to high in available K (290–354 kg $ha^{-1}$). Since 1975 land use patterns in the watershed have been relatively stable. The only significant change since the 1980s has been adoption of intensive agriculture. Present land uses in the study area consist of about 67% cropland and 33% forest. About 10 ha (5%) area in the valley landscape is under irrigated agriculture. The vegetation is predominantly secondary forest but there are remnant patches of primary forest especially on steep slopes.

### 2.2. Cropping pattern

The major crops grown in the area were barnyard millet (*Echinochloa frumantacia*) finger millet (*Eleusine coracana*), maize (*Zea maize*), wheat (*Triticum aestivum*), rice (*Oryza sativa*), and barley (*Hordeum vulgare*) in cereals; vegetable pea (*Pisum sativum*), potato (*Solanum tuberosum*), French bean (*Phaseolus vulgaris*) and cabbage (*Brassica oleracea* var. *capitata*) in vegetables; soybean (*Glycine max*) and lentil (*Lens culinaris*) in pulses; rapeseeds (*Brassica campestris*) and mustard (*Brassica juncea*) in oilseeds. In the upper and mid-slope regions, about 70–76% of the cropped area was occupied by cereals, 7–9% pulses, 2–5% oilseeds and 1% by vegetables. A considerable area in these regions was under traditional mixed cropping. In valleys, about 41.8% area was under cereals, 2.7% under pulses, 49.4% under vegetables and 6.1% under oilseeds. There was a fallow period of 6 months in the cereal crop rotations, especially after finger millet in all the three landscape regions.

### 2.3. Soil sampling and analysis

Bulk and core soil samples were collected from upper, middle, and lower landscape positions from randomly selected points in each land use types. Representative sample sites at forest and agricultural lands were adjacent to each other. They were spatially separated by 10–20 m within the same physiographic unit with similar slope and aspect. At each sampling point, three cores (5.0 cm diameter) were randomly taken within 1 m of each other to a depth of 15 cm. About 500 g composite soil sample was obtained after combining three cores at each point. A total of 60 composite soil samples were air dried and passed through 2 mm sieve, and selected soil attributes were determined. The bulk density ($\rho_b$) was measured by the core method (Blake and Hartge, 1986). The infiltration rate was measured by double ring infiltrometer using the water ponding method. Large clods of bulk samples were broken by hand into smaller segments along natural cleavages prior to air drying. The aggregates were sieved using the wet sieving technique (Yoder, 1936; Kemper and Rosenau, 1986). Soil water stable aggregates were assessed according to methods described by Cambardella and Elliott (1993) and expressed as aggregates > 1.0 mm. The remaining soil was ground and sieved through a 2-mm sieve, and 50 g of the sieved soil was used for particle size analysis by the hydrometer method (Gee and Bauder, 1986). Organic carbon content was determined by Walkley and Black method. Total N was measured with the Kjeldhal method and available P by ammonium acetate extraction, colorimetrically. Surface stoniness, vegetative cover and soil macro fauna were measured using 1 $m^2$ quadrate at each sampling site.

### 2.4. Statistical analysis

Measured data were analyzed by analysis of variance (ANOVA) using SAS statistical package (SAS Institute, 1992) to examine the effect of sites and land use types on overall soil performance. Statistical significance of each attribute was assessed using Fisher's least significant difference (LSD) at $P<0.05$ level.

### 2.5. Scoring functions and soil quality evaluation

In this study, soil quality was evaluated in terms of five soil functions: infiltration and redistribution of air and water; preservation of soil moisture; organic matter supply and nutrient cycling; habitat for flora and fauna; and resistance to erosion. The attributes measured to evaluate these functions are listed in Table 1. Mean values of all these attributes were transformed with non-linear scoring curves to unit less (0–1) scores that reflect performance of soil functions. The rationale for these scores is given in Table 2. Scoring curve consists of an algorithm or logic statement with alternative algorithms. For each scoring curve, the *y*-axis was a functional performance value. The *x*-axis represented the expected range for each soil attribute. The relationship dictates the shape of an indicator's scoring curve. Some general shape include a midpoint optima (GAUSSIAN), a sigmoid curve having a lower asymptote (model 1) or a sigmoid curve with an upper asymptote (model 2) represented the attribute's relationship to soil function which were determined by expert opinion as recommended in the literature (Karlen and Stott, 1994; Lal, 1996; Hussain et al., 1999; Andrews and Carroll, 2001; Andrews et al., 2002; Baja et al., 2002). Individual attribute scores were then multiplied by respective weights to create a weighted additive index of soil quality. The weights of attributes corresponding to each soil function were adopted from Ericksen and Ardon (2003).

## 3. Result and discussion

The distribution of native soils in the landscape, generally influenced by erosion, geological substrate and altitude, permitted the identification of various environments. However, some characteristics of soils under terraced agriculture are influenced by management practices including land use type. Table 3 showed the range and mean values of the physical and chemical indicators of soil quality under the main types of land use in each landscape environment. With the increasing elevation that is from valley to higher hills, soil pH and clay content decreased. Organic carbon (OC), total N, extractable P and available K increased because of elevation. Appreciable difference was observed in terms of bulk density, OC, infiltration rate, aggregate size fraction, mean weight diameter of soil aggregates, total N, extractable P and available K between the native condition (woodlands) and terraced agriculture in different landscape positions.