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Pedogenetic investigation of soil degradation on a deforested loess hillslope of Golestan Province, Northern Iran

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ABSTRACT

Genesis, mineralogy, and micromorphology of soils formed on a forest and adjacent cultivated loess hillslope were investigated to assess the effects of deforestation and hillslope position on soil properties and the intensity of soil degradation. The study revealed that deforestation caused a loss of soil organic carbon, a reduction of cation exchange capacity, and an increase in carbonates in the surface soil. The soils of the different slope positions of the forest land were Alfisols and Mollisols with well-developed argillic horizons. Speckled b-fabric of the argillic horizons and the crystallitic b-fabric of the underlying calcic horizon are evidence for a more stable landscape under forest ecosystem. Downward leaching caused decalcification of the upper horizons and clay movement in the profile. Formation of the mollic epipedon in the forest land confirms the accumulation of organic carbon and lower erosion in the surface soil. Soils of the adjacent cultivated area however, are less-developed, and classified as Inceptisols and Mollisols. Absence of the mollic epipedon in the shoulder, backslope and footslope positions, presence of the near surface calcic horizon and absence of argillic horizon in all slope positions are due to severe erosion. Absence of speckled b-fabric in all the slope positions of the deforested land is evidence that downward and surface movements of water have resulted in soil erosion and flooding. Higher smectite concentrations and occurrence of vermiculite in the forest area indicate favorable moisture availability. Pedology is an effective way of documenting the adverse effects of land use change especially in the hilly regions.

1. Introduction

Land degradation is defined as the temporary or permanent decline in the productive capacity of the land, and the diminution of the productive potential, including its major land uses, farming systems, and value as an economic resource (Stockings, 2004).

Forests around the world have undergone severe disturbances due to anthropogenic interference. The conversion of forestland to cropland, grazing land, and settlements has often resulted in soil degradation and nutrient losses (Dinesh et al., 2003). Drees et al. (2003) reported that 800 million people worldwide depend directly on steeplands for sustenance. Due to population pressures, the steeplands, which were largely forested, have been cleared for cultivation (Nyssen et al., 2009).

Loess soils are among the most fertile ones in the world. They often contain little clay, which leads to loss of organic carbon under cultivation; the resulting structural instability of the surface soil causes problems of crusting, poor germination of crops and erosion (Catt, 2001). Golestan Province is one of the most important agricultural areas in Iran, well known for its loess derived fertile soils. Hillslopes of Golestan Province are mainly reserved as natural forests.

Land use change and deforestation on loess hillslopes of Golestan have dramatically increased recently and are considered as the main causes of the floodings that resulted in loss of the lives of many people (Hadiani, 2007). The deforestation and cultivation on the loess hillslopes of Golestan Province of Iran have also resulted in a significant deterioration of soil quality. The average organic carbon (OC) stock of the 0–60 cm depth of the forest and deforested and cultivated area were, 184.8 and 58.8 ton ha^{-1}, respectively (Khormali et al., 2009).

Land use effects on the degradation of Mollisols in western Iran revealed that unlike rangelands, cultivated soils lack enough organic carbon to meet the requirements of Mollisols and have only ochric epipedons (Khormali and Nabiallahi, 2009).

Soil micromorphology can be a valuable tool to monitor some important soil quality changes. Micromorphological investigations revealed that the forest and rangeland soils had strong granular and crumb microstructure compared to the deforested land (Khormali et al., 2009).

Vera et al. (2007) reported that the forest study site had a predominance of aggregates of biological origin, reflecting the influence of the vegetal input and biological activity. In the deforested plot, thick laminar aggregates predominated, and there were small

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quantities of medium angular blocks with weak pedality that are evident both at the micro- and macromorphological levels, showing the impact of the mechanized deforestation on this soil.

Forest soil microfabrics confirmed the translocation of clay into the subsoil, accumulation of dense incomplete typic channel and pore coatings in the subsoil horizons and below 1 m indicate long-term landscape stability, even on landforms with slope gradients >20%. Therefore, historically, these landforms were not as susceptible to slump erosion as they are under current land management (Gunal and Ransom, 2006a).

Argillic horizons are usually associated with speckled b-fabric, indicating the downward leaching of calcite as a result of a more stable landform (Khormali et al., 2003). Gunal and Ransom (2006b) concluded that clay translocation and the formation of coatings in forest soils indicate the prior long-term landscape stability. This stable period was interrupted with the removal of the forest cover for the purpose of subsistence agriculture.

Clay mineralogy can be regarded as an indicator of landscape stability. Chlorite, illite, smectite, and kaolinite are observed in the clay fraction of the loess parental material (Khormali and Kehl, 2011). Illite (mica) constitutes the main part of all studied parental loess, and its presence in soils is mainly of detrital origin. In the typic xeric moisture regime regions of Golestan Province where the soil available moisture is higher (P/ET>0.4), smectite content increases which is believed to be mainly from mineral transformation (Khormali and Kehl, 2011). This is in line with the findings of DeAnn Ricks et al. (2010) for the central plains of Northern America.

Vermiculite is present in small amounts in the loess material (Khormali and Kehl, 2011). The occurrence of vermiculite in the forest land is due to higher leaching conditions and the removal of K, mainly from mica (Douglas, 1989; Egli et al., 2008). According to Boettinger and Southard (1995), moisture availability for chemical weathering and dampened temperature fluctuations provide favorable conditions for vermiculite stability, which may explain the high vermiculite contents in pedons of the humid part of the climosequence studied.

Bonifacio et al. (2009) states that clay minerals are frequently used as indicators of pedogenesis. Graham and O'Geen (2010) concluded that on the summit and backslope positions, biotite weathers to vermiculite, hydrobiotite (regularly interstratified biotite/vermiculite), and kaolinite.

Due to the importance of the loess hillslopes and their high extension in Golestan region of Iran, we attempted to study pedogenesis of the soils using physico-chemical properties, formation of diagnostic horizons, and micromorphology together with clay mineralogy to find: 1. the effects of deforestation and hillslope positions on the soil properties and 2. monitor the intensity of soil degradation.

2. Materials and methods

2.1. Site settings and sampling

The study area i.e Agh-Su is a part of the Gorganrood watershed located in eastern Golestan Province, Northern Iran (Fig. 1). The average annual soil temperature and precipitation are 16 °C and 600 mm, respectively. The soil moisture regime is xeric and the temperature regime is thermic (SWRI — Soil and Water Research Institute of Iran, 2000). The major parts of the study area are occupied by mountains and hills with the parent materials mainly composed of loess deposits.

The main plant species of the forest land are *Alanus subcordata*, *Parrotia persica*, *Carpinus betulus* and *Crataegus* sp. The farmlands are mainly under wheat cultivation. The history of deforestation goes back to almost 50 years. Ten pedons from different slope positions (summit, SU, shoulder, SH, backslope, BS, footslope, FS, and toeslope, TS) of a hillslope of both forest landuse (FO) and an adjacent deforested cultivated land (DEF) were dug, described and classified, according to the Soil Survey Manual (Soil Survey Staff, 1993) and Keys to Soil Taxonomy (Soil Survey Staff, 2010) (Fig. 2).

2.2. Laboratory analyses

2.2.1. Physical and chemical analyses

Particle-size distribution was determined using the pipette method (Day, 1965). Alkaline-earth carbonate was measured by acid neutralization (Salinity Laboratory Staff, 1954). Organic carbon was determined by wet oxidation method (Nelson, 1982). Soil pH was measured in a saturation paste and electrical conductivity was determined in a saturation extract (Salinity Laboratory Staff, 1954). Cation exchange capacity (CEC) was determined using sodium acetate (NaOAc) at pH 8.2 (Chapman, 1965).

2.2.2. Micromorphological analyses

Thin sections were prepared from air-dried, undisturbed and oriented clods using standard techniques described by Murphy (1986). Micromorphological descriptions and interpretations were made according to Bullock et al. (1985), Stoops (2003) and Stoops et al. (2010).

2.2.3. Mineralogical analysis

The removal of chemical cementing agents and separation of the clay fractions were done according to the methods of Kittrick and Hope (1963) and Jackson (1975). The carbonates were initially removed using 1 N sodium acetate buffered at pH 5. The organic matter was then oxidized by treating the carbonate-free soils with 30% H_2O_2, and digestion in a water bath. Free iron oxides were removed from samples by the citrate dithionate method of Mehra and Jackson (1960).

The clay separates were removed by centrifuge and studied by a Bruker D8 Advance X-ray diffractometer using Cu Kα radiation (40 kV and 30 mA), a step size of 0.02° and a time per step of 1 s. To identify kaolinite in the presence of trioctahedral chlorite, samples were also treated with 1 N HCl at 80 °C, overnight. The semi-quantitative percentages of the clay minerals were estimated according to Johns et al. (1954), based on the relative peak areas of the glycerol solvated treatments.

3. Results

3.1. Soil classification

Table 1 presents the major morphological, physico-chemical and micromorphological analyses along with the classification of the soils on each geomorphic surface of both land uses. Particle size distribution of the loess parent material includes high content of silt (Table 1). Most of the FO soils show well developed argillic, calcic horizons and mollic epipedons and are classified as Calcic Argixerolls (pedons 1, 5 and 7 of SU, BS, and FS), Typic Haploxeralfs (pedon 3, SH), and Typic Calcixerolls (pedon 9, TS).

Solum thickness is high and mostly exceeds 2 m, so that no C horizon is detected in the studied pedon depths. Major horizons of the DEF soils are calcic (pedons 2, 6, 8, and 10 of SU, BS, FS and TS respectively). They are mainly classified as Calcixerolls and Calcixerepts. In the deforested land use no argillic horizon is observed, except for the FS position which is a buried horizon.

Pedon with minimum development is detected on the SH position of DEF. This soil was classified as Typic Haploxerepts with a thinnest solum (60 cm) and a very weak cambic horizon. Another feature observed in the TS of DEF is the presence of aquic conditions which is proved by the presence of a perched water table at 120 cm depth and also redoximorphic features.

The reaction classes of the soils of the DEF are all alkaline showing no carbonate depletion. In FO, however, nonacid reaction class was