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Andisols of Turkey: An example from the Cappadocian Volcanic Province

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ABSTRACT

A number of studies have been conducted on the genesis of soils from volcanic deposits in semi- humid and humid climates. However, there has been little study of the mineralogical properties and genesis of soils from volcanic rocks in arid and semi-arid climates. This study was conducted to understand the genesis of soils from different volcanic parent materials, such as andesite, dacite, volcanic ash, basalt and ignimbrite, in the region east of the Erciyes stratovolcano in Central Anatolia. At least three soil profiles were selected from each parent material, and 17 soil profiles were described. Soil samples were also taken from each soil horizon for physical, chemical and mineralogical analyses. Soil profiles vary according to elevation and the types of derived-parent materials and are divided into 17 pedons and 15 horizons (2A, 2Bw, 2Bw1, 2C, A2, BC, Bw, Bw1, Bw2, Bw3, C, C1, C2, Cr, R). Soil acidity varied from slightly alkaline to slightly acidic in all soils. Organic matter contents were higher in the surface horizons and generally decreased with depth in all pedons. The extractable cation values of ammonium oxalate, pyrophosphate, dithionite-citrate and sodium pyrophosphate, as well as un-hydrolyzed volcanic glass, allophone, imogolite, smectite and ferrihydrite contents of the soils, are variable based on the parent materials, pedons and elevations that are typical of the Cappadocian volcanogenic soils in Anatolia of Turkey. These soils can generally be described as alu-andic Andisols, due to their Al_o + 1/2Fe_o values and Al_p/Al_o ratios. The important factors affecting the formation and development of soils are climatic variations affecting horizon development and genesis, soil parent material diversities and leaching regimes originating from elevation differences.

1. Introduction

Andisols cover approximately 1.2 million km^2 globally (Kimble et al., 1999), occur under various climatic conditions and reflect the properties of volcanoclastic materials or tephra as their parent material (Shoji, 1986). It is known that volcanic ash soils have different morphological, physical, chemical and mineralogical properties compared to other soils (Wada, 1985). Volcanic ash soils are specifically characterized by soil properties such as low bulk density, a specific surface area of approximately 600 m^2 g^{-1}, high water and phosphorus retention, high cation exchange capacity and organic carbon content (Parfitt and Clayden, 1991; Allbrook and Radcliffe, 1987; Shoji et al., 1993, 1996; Chen et al., 1999). The physical and chemical properties of volcanic ash soils are influenced by the presence of imogolite, allophane, halloysite and amorphous materials (Shoji et al., 1993; Nizeyimana et al., 1997). The dominant pedogenic process related to the formation of Andisols is the development of non-crystalline materials and accumulation of organic carbon (Shoji et al., 1993). The term "andosolization" has been used for this process occurring preferentially in volcanic ash (Duchaufour, 1984).

The formation of non-crystalline materials in soils formed on volcanic parent material is connected to the properties of volcanic ash or tephra (Shoji et al., 1993). The type and amount of these materials is related to the age and character of the parent material (Parfitt and Wilson, 1985). The rate of weathering depends on numerous factors, such as the amount, size, porosity and chemical and mineralogical composition of the weatherable primary materials, especially volcanic glass (Van Ranst et al., 1993; Shoji et al., 1993). The type and amount of constituents in volcanic ash differ according to the ratios of precipitation (Parfitt et al., 1984; Parfitt and Kimble, 1989; Ugolini and Dahlgren, 1991). Allophane and imogolite are dominant in soils of humid climates, whereas halloysite dominates in soils of lowest rainfall

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climates (Shoji and Fujiwara, 1984; Parfitt and Kimble, 1989; Shoji et al., 1996; Nizeyimana et al., 1997). Van Ranst et al. (2002) assessed the influence of changes in the parent ash material for a number of physico-chemical properties of Andisols in Java. They attributed the decrease in soil pH and exchangeable Ca from East to West Java to the combined effect of the parent ash becoming more acidic from east to west and the more pronounced seasonality in East Java.

Climate and time are two important factors for volcanic soil formation. Volcanic soils can form in different climatic conditions. Volcanic soils that form in arid and semi arid climates have not been investigated as much as those forming in wet climates (Georgoulias and Moustakas, 2010). Noncrystalline components (allophanes, imogolite, amorphous hydroxides and amorphous silicates) and organic matter accumulation are main soil formation processes in most of the volcanic areas (Shoji et al., 1993). The type of noncrystalline component depends on main material, climatic conditions and level of weathering (Drouza et al., 2007; Wada, 1989). Soil formation processes differ in arid and semi arid climates. At first, coarse minerals divide to smaller fragments. The next step is formation of diagenesis products which interact with main materials (Dubroeucq et al., 1998). The period of andic character in volcanic soil formation is shorter under semiarid conditions (Jahn, 1991). Egli et al. (2008) indicated that in the soils which formed from volcanic main material, transformation can occur as volcanic glass-imogolite like allophones- halloysite- kaolinite. Noncrystalline components can transform into halloysite-kaolinite and gibbsite according to increase of the breakdown (Georgoulias and Moustakas, 2010).

Many studies in different parts of the world related to volcanic ash soil have been conducted (e.g., Wada, 1980, 1985; Parfitt and Clayden, 1991; Shoji et al., 1993, 1996; Van Ranst et al., 2002, 2008; Kleber et al., 2004). These studies reflect the original features and characteristics of the soils in each region studied. Areas where volcanic mountains are present often have the udic and perudic or xeric moisture regimes of the Mediterranean climate. There have been almost no investigations conducted relating to volcanic ash soils that form in warmer and less rainy climates. Sufficient research on Andisols formed in the different climatic and temperature regimes in Turkey has not yet been done at the international level, though some researchers have evaluated the formation, classification and definition of Andisols (e.g., Kapur et al., 1980; Çavuşgil et al., 1986; Dingil, 2003). Information on soils formed on volcanic parent material in Turkey, especially in the Cappadocian Volcanic Province (CVP), is not included in the World Reference Base for Soil Resources (WRB) (Eswaran et al., 2003). For this reason, the present study aims to develop an additional tool for the description of the Andisol type of soils by using structural, textural, mineralogical and chemical features.

2. Materials and methods

2.1. Description of the study area

This research was carried out on soils formed on different volcanic parent materials in the CVP of Turkey, which covers about 18,000 km^2; a 2400 km^2 portion of this region located to the east of the Erciyes stratovolcano as the study area. There are five main volcanic parent materials in the study area according to the geological map prepared by Şen et al. (2003): andesite, dacite, volcanic ash, basalt and ignimbrite (Table 1, Fig. 1). Dacite is located at the high elevations (2600 m above sea level) of the Erciyes stratovolcano, and the other parent materials are in the lower elevations (Fig. 1). The slopes are between 1 and 60% and the elevations range from 1100 to 2800 m above sea level. The average precipitation is 300–420 mm/year, with a maximum 600 mm/year in the western region of the study area, where the soils are under different types of land use with grassland, pastures, arable fields, horticulture and dry and irrigated agricultures (Fig. 2).

2.2. Soil sampling and laboratory analysis

The study area was stratified using the results of initial (field) surveys, archive LANDSAT-ETM + images, a digital elevation model with 1/25,000 scale, a geologic map with 1/25,000 scale and digital soil maps. The reason for this stratification is to determine the soil profile sites. At least three soil profiles were selected from each parent material for characterization, representing a variety of geomorphic surfaces in the study area. A total of seventeen soil profiles were described and soil samples were taken from each soil horizon for physical, chemical and mineralogical analyses. Samples were air-dried, ground and sieved through a 2 mm sieve. The pipette method was used for determining the particle-size distribution, and the bulk density was measured by the core method. The pH was measured in water (1:1), 1 N KCl (1:1) and

Table 1
The features of the study areas in the Cappadocian volcanic province.

Profile	Elevation (m.a.s.l.)	Aspect	Slope (°)	MAT (°C)	Annual precipitation (mm)	Parent material	Vegetation	Time of deposition years (ma)
1	1435	W	3	8	300	Ignimbrite	Meadow grasses	2.7 ± 0.1
2	1462	E	1	8	300		Wheat field	2.7 ± 0.1
3	1457	S	1	8	300		Wheat field	2.7 ± 0.1
4	1431	S	2	8	300		Wheat field	2.7 ± 0.1
5	1545	E	3	7	400	Andesite	Wheat field	2.8 ± 0.1
6	1453	S	1	8	300		Wheat field	2.8 ± 0.1
7	2124	N	5	5	550		Meadow grasses, astragalus	2.8 ± 0.1
8	2222	E	7	5	550		Meadow grasses, astragalus	2.8 ± 0.1
9	1538	E	1	7	400	Basalt	Meadow grasses, astragalus	3.0 ± 0.1
10	1477	S	1	8	350		Wheat field	3.0 ± 0.1
11	1451	E	2	8	300		Wheat field	3.0 ± 0.1
12	2712	E	0	1	600	Dacite	Meadow grasses, astragalus	0.9 ± 0.2
13	2662	E	0	2	600		Meadow grasses, astragalus	0.9 ± 0.2
14	2561	N	0	3	600		Meadow grasses, astragalus	0.9 ± 0.2
15	1824	E	0	6	500	Volcanic ash	Meadow grasses, astragalus	0.13 ± 0.02
16	1599	E	7	7	450		Wheat field	0.13 ± 0.02
17	2002	E	0	5	550		Meadow grasses, astragalus	0.13 ± 0.02