Morphological and Physical Properties of Fragipan in Contrasting Material Derived Soils

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Abstract

A study on properties of fragipan in soils derived from contrasting materials, wash and colluvium of sandstone overlying residuum of tuff, was conducted in the area of Farmer Occupational Research and Development Center, Kasetsart University, Panead subdistrict, Khok Samrong district, Lopburi province. Two sampling transects along different toposequences across the footslope of a sandstone mountain were chosen for the study, objectively to investigate field morphological and physical properties of the fragipan. There were five soil profiles selected for each transect across the footslope in addition with two soil profiles situated on the north of these transects. Standard procedures were employed for characterizing field morphology and determining physical property in laboratory. Results revealed that all soils are very deep, occupying sloping surface ranging from 1-5%. They have coarser texture in the upper part than do in the lower part of the profiles. Their soil color pattern is rather similar. They have lower pH value (4.5-6.5) in the upper sandier-textured horizons than in the lower layers (6.5-8.0). Fragipan found in all soils with varying thicknesses and depths was formed directly underneath soil layers that were derived from short distance deposit of sandstone material eroded from the upper slope. Materials in fragipan layer, designated by Btx, are brittle and slaking in water. This pan has very to extremely low saturated hydraulic conductivity (0.51-0.0002 cm hr^{-1}), which coincides with high bulk density values (1.58-1.90 Mg m^{-3}). Dry soil strength of fragipan layers varies between 0.46-2.02 MPa, indicating that most of the fragipan layers found in the study can have negative impact on plant roots.

Keywords: fragipan, toposequence, footslope, sandstone, tuff

Introduction

Fragipan is recognized by both the World Reference Base for Soil Resources (IUSS, 2006) and the Soil Taxonomy (Soil Survey Staff, 2006). Fragipans are subsurface horizons that naturally occur. They are dense, brittle when moist, root restrictive and slowly or very slowly permeable (Soil Survey Staff, 1999). Witty and Knox (1989) suggested a revised definition of a fragipan that should be stressing on brittleness, slaking, absence of roots, evidence of pedogenesis such as mottles, clay films and vertical streaks and the presence of prisms defined by vertical gray streaks or tongues. Brittleness has been cited as one of the most diagnostic properties of fragipan, but its determination is subjective to and dependent on moisture condition at the time of sampling (Smeck and Ciolkosz, 1989; Pickering and Veneman, 1984). In general, most parent materials of fragipan give either loamy (Hallmark and Smeck, 1979; Scalenghe et al., 2004) or heterogeneous texture (Olson et at., 1967) and some authors have reported similar textures (loamy sand, sandy loam, and loam) for fragipans formed in glacial drift (Yassoglou and Whiteside, 1960; Vaneman and Bodine, 1982; Habecker et al., 1990; Miller et al., 1993). Most fragipans have an abrupt or clear upper boundary at a depth of 50 to 100 cm below the original soil surface where erosion may have taken place. The thickness of this pan commonly ranges from about 15 to 200 cm (Soil Survey Staff, 2006, 2010). According to the studies cited above, the fragipan tends to develop in a contrasting material. This study was objectively to investigate morphological characteristics and physical properties of fragipan found in a particular area and to relate them with soil parent material and position on the landscape.

Materials and Methods

Location and General Information of the Site

The study area encompasses footslope of a sandstone mountain with coordinations ranging from the highest to the lowest position are 47 692000^{E} - 47 693000^{E} and 16 63800^{N} - 16 64800^{N} for the coordinations across the slope. The site studied is located in Farmer Occupational Research and Development Center of Kasetsart University. The center is situated in Central Highland region of Thailand (Kheoruenromne, 1991), having approximate total area of 300.2 hectares. Elevation of the area ranges from 46-62 m. This area is under a tropical savannah climate (Aw) with an average annual rainfall of 1,055.3 mm and mean temperature of 28.02ºC (Meteorological Department of Thailand, 2007). Two sampling lines were on different topo-sequences with five soil profiles chosen within each line. Additional two soil profiles on nearly the same contour line as of those on the middle of each toposequence were also selected for this study. The soils studied were mainly used for agricultural production with some soils being under native forest and left idle (Figure 1).

Sampling

One hundred and three samples were obtained from 12 soil profiles (Figure 1). Pedon analysis was carried out at each site, including detailed profile description and soil sampling with respect to soil genetic horizons (Soil Survey Staff, 2006, 2010; Kheoruenromne, 1991). Disturbed and Undisturbed soil samples were collected for soil physical analysis.

Physical Analysis

Bulk soil samples were air-dried and crushed to pass through a 2-mm sieve for laboratory analysis. Particle size analysis was determined by pipette method (Gee and Bauder, 1986). Undisturbed core samples were used to determine bulk density (Blake and Harte, 1986) and saturated hydraulic conductivity (Klute and Dirken, 1986). Unconfined compressive strengths of soil were measured on rectangular blocks roughly cut by hacksaw then stresses were measured by a load cell (Northey and Schafer, 1974).

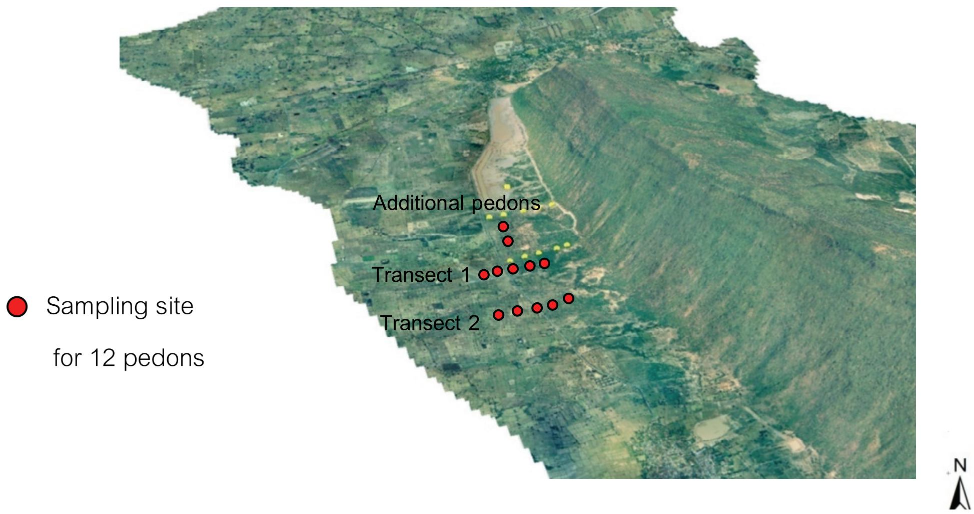

Figure 1 Sampling sites located on footslope of a sandstone mountain

Results and Discussion

The Environmental Setting of the Soils

The location of soil profiles in each transect can be divided into three physiographic positions; upper, middle and lower footslopes. These soils have contrasting parent materials, colluvium and wash derived from sandstone overlying tuff residuum. Within transect 1, soils are on concave sloping surface whereas those in transect 2 are mainly situated on convex sloping surface and additional pedons are on erosional surface of upper middle footslope. All soils are very deep and moderately developed. They have well drained feature, moderate to rapid permeability and rapid runoff.

Field Morphology of Soils

Soil Profile Development

Profile development of these soils studied is genetically A(Ap)-(E)-(Bt)-2Btx. Some subsoil layers contain concretions and harden plinthite as indicated by Btc and Btv, respectively. Clay accumulation in subsoils can be well observed in the field. Clay coatings on ped faces and clay bridges between sand grains are indicative of clay illuviation (Buol et al., 2002). Clay bridging has also been reported as a feature for fragipan cementation (Romans, 1962; Nettleton, 1968; Hallmark and Smeck, 1979; Wang et al., 1974). A presence of Fe-Mn nodules indicates the wetting and drying condition in some parts of the soil profiles. Btx horizon was found in all soils studied. This horizon represents fragipan of which the layer evidently becomes harder than that of the overlying horizons. Also, it slakes in water, which is in contrast to duripan (Soil Survey Staff, 1999). This fragipan (2Btx) was derived from contrasting material, namely tuff (Soil Survey Staff, 1993). All of 2Btx horizons have firm to very firm consistence and they are brittle when moist with abrupt and smooth horizon boundary delineated from overlying coarser materials. This particular horizon is found at the shallower depth on the higher landscape position. The thickness of this pan differs between the two transects. In transect 1, the pan occurred at the depth shallower than 100 cm in transect 1 whereas in transect 2, it was found between 98-129 cm from the mineral soil surface and between 110-132 cm in the case of additional two pedons.

Soil Structure

Soils with non fragic property have subangular blocky and angular blocky structures whereas prismatic and angular blocky structures characterize fragipan as defined by Soil Survey Staff (1999) which can be quite commonly found (Ciolkosz and Waltman, 2000) and may have been attributed by sodium in this case, which is generally high in this type of soil structure (Buol et al., 2003).

Soil Color

The colors of the overlying horizons (sandstone derived material) and the lower horizon (fragipan) are rather similar. Hue of soil matrix is yellowish brown to brown (7.5 YR-10YR) with a presence of red to dark red (2.5YR-10R) mottles. There are some darker color spots of organic material accumulation and red color of Fe-Mn nodules in all soil profiles. In addition, iron is segregated in the soils to form brownish yellow and strong brown mottles. The segregation in soils occurred as a result of pedogenic processes (current or relict) under wetting and drying conditions (McDonald, 1990). Those dominated by iron are recognized as ferruginous segregations which were most common in soils of the tropical and sub-tropical regions (Singh and Gilkes, 1996). This is similar to the soils studied. Soil profiles within each transect are formed under well drained condition, resulting in yellowish brown to brown color with few mottles in the upper part of the soil profiles whereas the lower horizons have more mottles, indicating that this part of soil solum is seasonally under wetting and drying condition periodically. Yellow or red color in these soils indicates the presence of iron oxides in different forms (Schwertmann, 1993). Dark brown or black color of topsoil layers signifies the accumulation of organic matter (Schulze et al., 1993).

Soil pH

Field soil pH of sandstone-derived horizons ranges from 4.5 to 7.0 while higher pH up to 8.0 is found in the lower part where soil parent material is derived from tuff. $CaCO_3$ nodules are also present in this sedentary material and are probably subjective of the high pH. The fragipan has higher pH than does the overlying horizons. This might be due to 1) the rate of leaching in the area which is not severe due to low amount of rainfall (less than 1,000 mm in most years) as indicated by the presence of $CaCO_3$ nodules, prismatic structure and sodium in soil solution, and 2) tuff derived material that usually comprises high amounts of Ca, Mg and K.

Depth of Fragipan

Although all soils at all positions of the landscape are deep, the thickness of fragipan and the depth at which this dense layer occurred are different. The lower the position of footslope landscape, the deeper the fragipan can be found (Figure 2), mainly owing to erosion that carries soil materials from the upper part to deposit onto the lower areas such as on the lower footslope. This is similar to the study by Chen et al. (1980). They found that the fragipans occurred after soil erosion was found in the area nearby in addition to the study of Graveel et al. (2002) that their studied soils had fragipan at shallow depth. Their profile modification had occurred as a result of soil erosion.

Other Features

Fragipan layers have sandy clay loam to sandy clay texture. Fe-Mn oxide and $CaCO_3$ nodules are also found in this dense layer. These pans are extremely hard when dry, brittle and firm when moist, having very sticky and very plastic consistence when wet. The hard when dry characteristic is consistent with the property proposed by Lindbo and Veneman (1989), and Weisenborn and Schactzl (2005) as well as firm resistance (Soil Survey Staff, 1999). There is practically no root in fragipan layers found in this study. Root development may be adversely affected by the strongly compacted condition that is generally a characteristic of fragipan horizons as defined by Soil Survey Staff (1999). All fragipans in this study contain very fine vesicular pores with some layers also having very fine simple tubular pores. This commonly contributes to the fragipan layer to have low or very low permeability (Olson, 1985; Daniels and Fritton, 1994) and low moisture retention (Mehuys and De Kimpe, 1976).

Physical Properties

Particle Size Analysis

All soils are dominated by sand particles with low to moderate silt and clay contents (Table 1). Contrasting material together with clay translocation results in changes of soil texture from loamy sand or sandy loam in the upper soil solum to sandy clay or sandy clay loam in the lower part of the soil profiles, particularly in the fragipan layers. This is because the coarser-textured layers developed from transported materials of sandstone eroded from the higher part of the landscape, mainly from the sandstone mountain and the upper footslope. Tuff, a type of rock consisting of consolidated volcanic ash ejected from vents during a volcanic eruption, as parent material of soil in the lower part of the soil profiles is responsible for the more clayey texture of this part of soil profiles. In addition, clay translocation partly has the effect on more amount of clay particle in this part of the soil profiles. It has been reported that some of the properties of some fragipans are inherited from buried paleosols (Soil Survey Staff, 1999; Bryant, 1989), which is the case as found in this study.

Bulk Density

All soils on transect 1, transect 2 and additional pedons have bulk density values ranging from 1.43-1.86, 1.25-1.90 and 1.43-1.88 Mg m^{-3}, respectively (Figure 2). The values increase with increasing depth with the highest values (1.86-1.90 Mg m^{-3}) being found in the fragipan horizon in all soils. This conforms well with other studies (Lindbo and Veneman, 1989, 1993; Rhoton and Tyler, 1990; Lindbo, 1990; and Miller et al., 1993, Graveel et al., 2002; Certini et al., 2007) where horizons with fragic property have higher bulk density than do the overlying horizons of all pedons. This can, to a certain degree, be the effect of clay translocation in their profiles (Marshall and Holmes, 1979; Owens and Watson, 1979; Calverts et al., 1980) and the movement of fine materials from the upper slope to the lower position (Moniz and Buol, 1982).

Table 1 Mean of particle size analysis.

Transect	Sand ($g\ kg^{-1}$)		Silt ($g\ kg^{-1}$)		Clay ($g\ kg^{-1}$)		Texture class
	Range	Mean	Range	Mean	Range	Mean	
Transect 1:							
Overlying horizon	550-760	681.4	153-258	197.5	62-229	120.8	SL to SCL
Fragipan	466-773	556.2	74-394	232.6	141-311	211.0	SL to CL
Transect 2:							
Overlying horizon	662-839	755.2	93-216	144.7	30-172	101.8	LS to SCL
Fragipan	526-777	628.2	121-246	173.2	111-279	213.2	SL to SCL
Additional pedons:							
Overlying horizon	484-775	622.2	139-260	187.9	86-425	190.1	SL to C
Fragipan	325-606	446.2	209-328	277.6	185-347	275.6	SL to CL

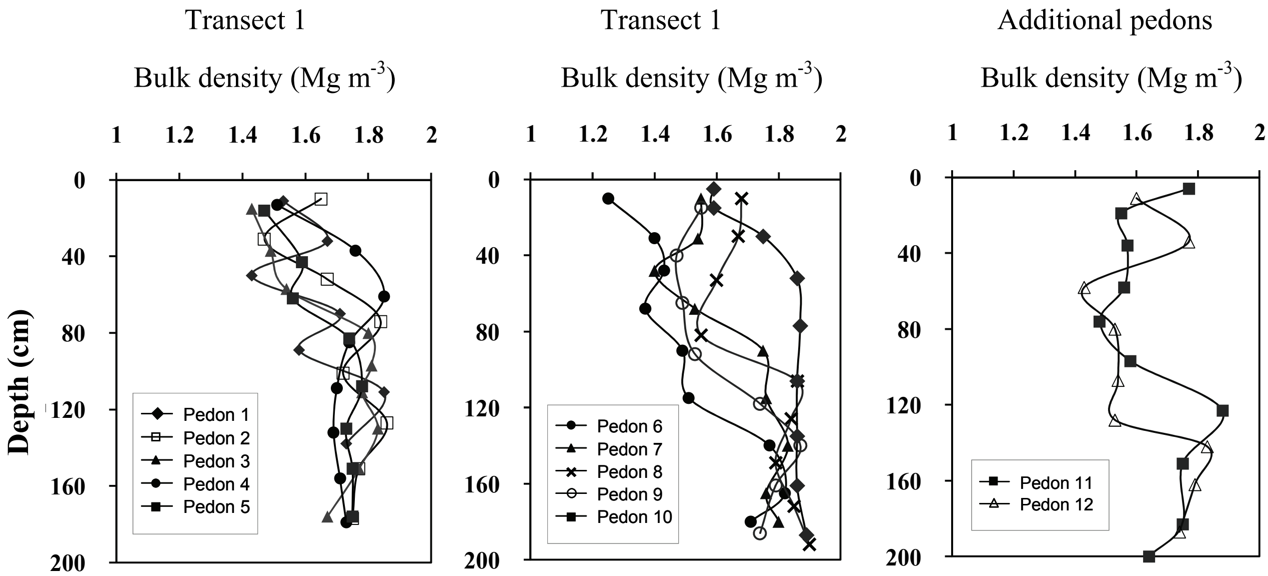

Figure 2 Trend of bulk density within soil profiles.

Total Porosity

The range of total soil porosity of all soils was between 29-53%. Fragipan is less porous (29-34%). The values tended to decrease in 2Btx horizons with the lowest percentage being in tuff derived material that has fragic property, which is in contrast to layers being composed of wash or colluviated materials that had roughly 10% more of total porosity. This is due mainly to very fine and fine sand plus silt particles filling up soil pores, resulting in a reduction of total porosity in fragipan. The lower porosity is relevant to high bulk density (Brouwer and Anderson, 2000; McNabb et al., 2001) as inversely relative with bulk density in all soils (r^2 = 1) as shown on Figure 3 (Bugbee and Frink, 1983; Bunt, 1988).

Saturated Hydraulic Conductivity

All soils have very slow to moderately rapid saturated hydraulic conductivity. All overlying horizons have higher hydraulic conductivity than do fragipan horizons (Figure 4). The latter has very low values varying from 0.004 to 0.18 cm hr^{-1}. These very slow hydraulic conductivity values are

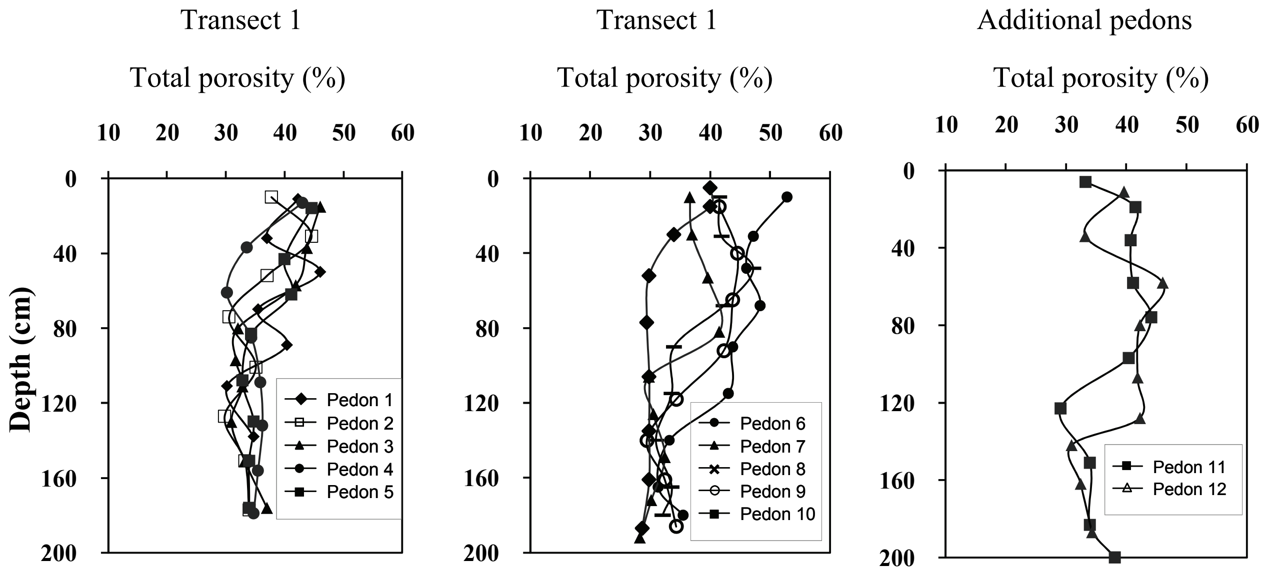

Figure 3 Trend of total porosity within soil profiles.

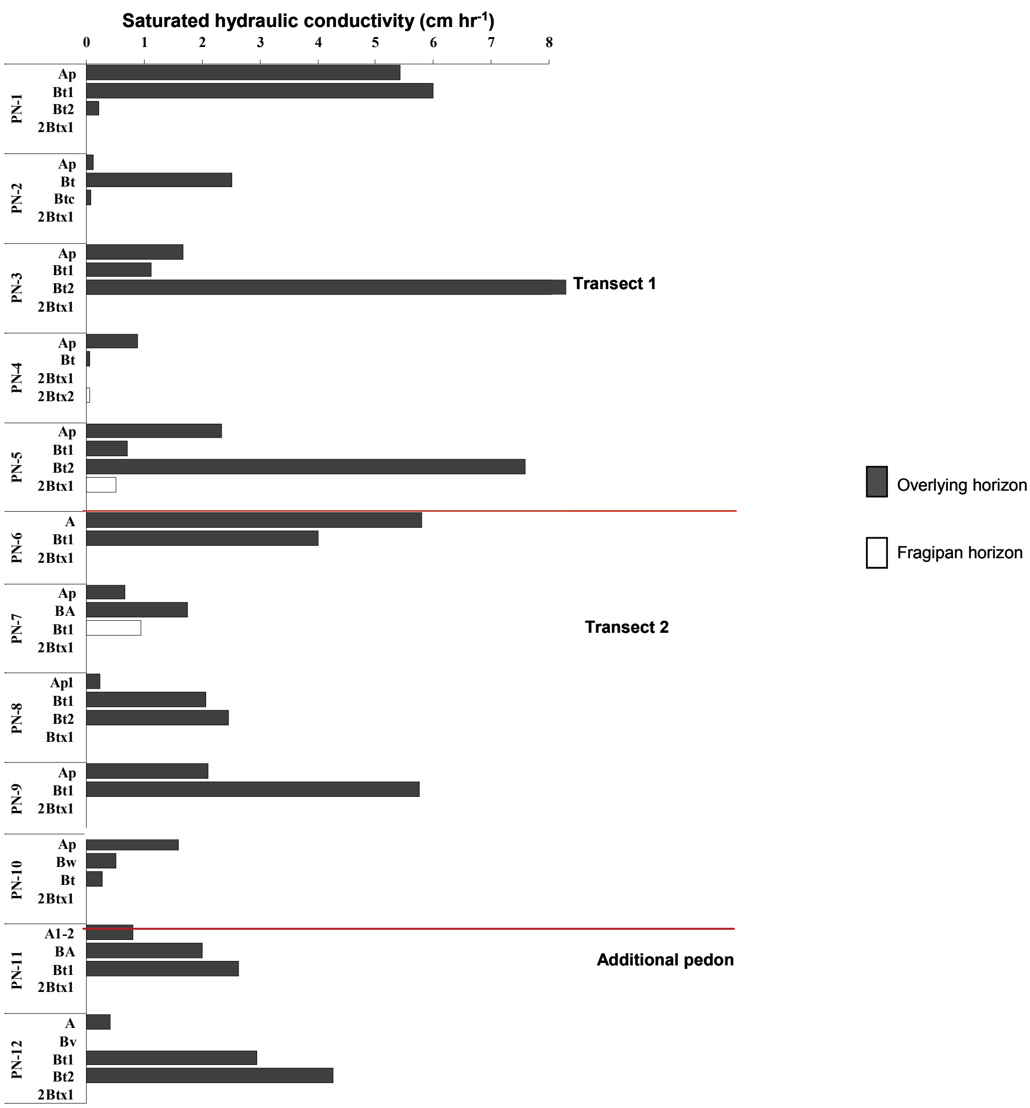

Figure 4 Saturated hydraulic conductivity of top four layers in all soils studied.

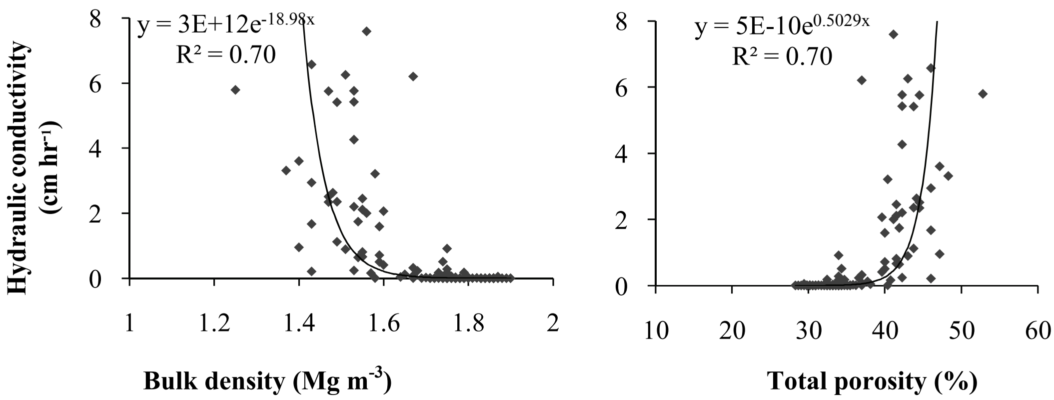

Figure 5 Correlations between saturated hydraulic conductivity and bulk density, saturated hydraulic conductivity and total porosity.

consistent with low porosity and high bulk density (Iwata et al., 1995; Hillel, 1998; Juma, 2001) as shown by the positive (r^2 = 0.7) and negative (r^2 = 0.7) correlations, respectively (Figure 5). Macropores in Ap horizon, many of which appear to be biological in nature and high sand content, are likely responsible for the higher hydraulic conductivity values (McDaniel et al., 2008).

Soil Strength

Results of the soil strength test show that 2Btx horizons in transect 1 have the strength ranging from 0.46-2.02 MPa with the ranges of 0.64-1.29 and 0.51-1.34 MPa obtained from transect 2 and additional pedons, respectively (Figure 6). The strength of these soils tends to increase with depth. This is very common that fragipan horizon has greater rigidity than do the overlying horizons (Well and Northey, 1985; Selim et al., 1987; Habecker et al., 1990; Norfleet and Karathanasis, 1996). The strength values of greater than 0.5 MPa can simply retard root penetration (Passioura, 1991). Based on the values of soil strength shown in Figure 6, the fragipans in these soils are extremely dense; hence root can hardly penetrate through this zone. According to study of Taylor and Ratiff (1969), cotton root growth was restricted when soil had penetration resistance of 0.72 MPa and root growth virtually ceased when soil had penetration resistance more than 3.0 MPa (Taylor and Gardner, 1963; Lowry, 1970). Iigima et al. (2003) found that root of maize elongation rate in compacted soil with penetration resistance of 1.0 MPa was only about half in length as compared to the root of the plant grown on loose soil with penetration resistance of 0.06 MPa. Commonly if soil has penetration resistance of less than 0.5 MPa, it has no effect on root growth (Hunt and Gilkes, 1992).

The Relationship between Soil Strength and some other Soil Properties

There are some physical factors which has been associated with the strength of soils. In this study, it is found that bulk density also closely relates to fragipan strength (r^2 = 0.24, 0.66 and 0.40 in transect 1, transect 2 and additional pedons, respectively) as reported elsewhere (Selim et al., 1987; Inman et al,. 1989; Norfleet and Karathanasis, 1996) (Figure 7). The positive correlation between shear strength and bulk density is thought to be due to the increased interlocking of particles and thus greater angle of internal friction in the soils with higher bulk density. McCormack and Wilding (1979) found that at high moisture content bulk density had, however, less influence on shear strength than at low moisture content.

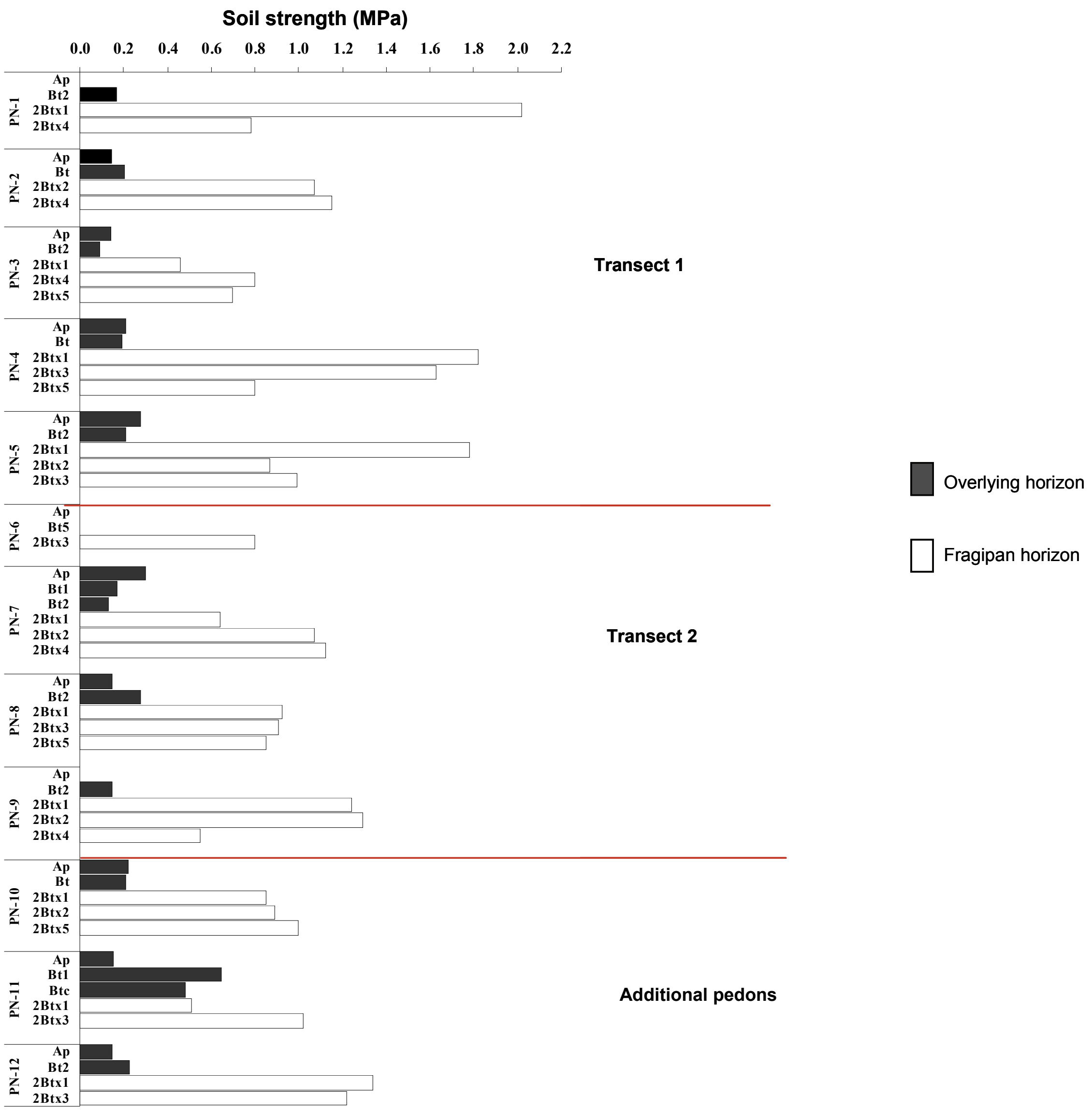

Figure 6 Soil strength of some soil layers in soils studied.

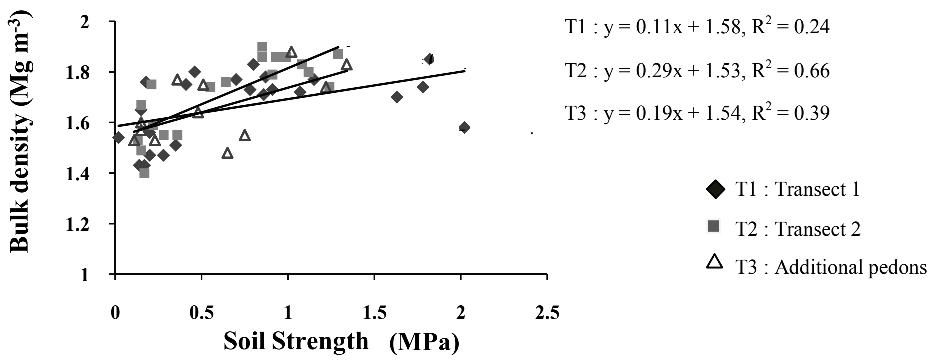

Figure 7 Correlations between soil strength and bulk density of soil.

Conclusions

Fragipans found in this study had been formed from contrasting materials, colluvium and wash derived of sandstone overlying residuum derived from tuff. Different type of parent materials contributes to different textural classes between the upper horizons and the fragipans. The fragipans contain more clay content than do the overlying horizons, mainly due to clay translocation and in-situ tuff-derived material. General morphological characteristics of fragipan among soils on different position of the landscape and between transects are rather similar except for thickness and depth from the mineral soil surface where the fragipan occurs. This mainly due to soil erosion which carried eroded sediments from the mountain and the upper footslope to deposit unequally on the lower areas. Field soil pH in the fragipan layers is greater than those transported materials. Features such as slaking in water, hard when dry, brittle and firm when moist, and prismatic structure of these dense layers in all soils meet the definition of fragipan and are similar to those previously reported. This pan has very to extremely low saturated hydraulic conductivity, low total porosity, and high bulk density. Saturated hydraulic conductivity has negative correlation with bulk density and positive correlation with total porosity. Strength of fragipans, clearly having positive correlation with bulk density, is greater than 0.5 MPa, indicating that these materials can become impenetrable for plant roots, particularly during low moisture period.

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