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# Macro morphological features of vertisols in semi-arid climate, in Rahad Area, Eastern Sudan

**Bushra Mohamed Meheissi**

Land and Water Research Centre, Wad Medani, Sudan.

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**ABSTRACT**

The study area lies in the eastern part of the Central Clay Plain of Sudan. The plain is dominated by the vertisols; which is cracking clayey soils with a dark colour. The study objective was to investigate macro morphological features of vertisols in semi-arid climate in eastern Sudan. The paper is limited to the description of surface and macro morphological features of vertisols. These features are: mulch of the soil surface, gray nodules, cracking, colour, texture, structure, calcium carbonates $CaCO_3$, calcareousness, consistence, porosity, and subsoil vertic features. The mulch thickness ranges from 1 to 5 cm. The soil cracks were observed throughout the area with width ranging from 1 to 7 cm; and depth of more than 60 cm. The gray nodules ($CaCO_3$) are common or abundant on the soil surface with different shapes and sizes. The colour is dark brown (10YR3/3) (70%), followed by very dark grayish brown (2.5Y 3/2) (30%). The texture class of these soils is heavy clay; where the clay percent is more than 60%. Soil structure of more than 95% of the soils have moderate grade of structure on the top, weak grade beneath, and massive at lower depths. Soil consistence is hard dry; friable moist, and very sticky and very plastic wet. The parallel-epipedal structural aggregates appear between 40 and 50 cm of the profile soil depth. The slickenside appears at 60 cm and downwards with distinct feature below the cracking zone. Soil pores are common to few; very fine, fine micro pores, and very few medium meso pores. The macro pores exist at deeper moist subsoil where biological activity present. Calcium carbonates ($CaCO_3$) are few to common and occurred in a wide variety of forms as concretions and soft segregates, and increases with soil depth.

**Keywords:** Macro morphology, vertisols, semi arid, Rahad.

E-mail: bushrat77@yahoo.com.

## INTRODUCTION

Vertisols are the dominant soils of the Central Clay Plain in Sudan. It is the main soil of agricultural schemes in Sudan: as Gezera, Kanana. Rahad Halafa schemes. The Central Clay Plain is located between latitudes 16° N and 10° N and longitudes 32° E and 37° E. It extended over vast areas of the country where it covers most of the central states in Sudan. Vertisols are the heavy clayey, cracking, and dark brown soils and locally known as Baduba. The parent materials for these soils belong to two broad groups: alluvial, deltaic and paludal sediments from rivers belonging to the Nile system (aggradational clay plains), and colluvio-alluvial deposits derived from local rock weathering, pediplanation and short-distance transport (degradational clay plains) (Blokhuis, 1993). The origin of these soils in the eastern part of the plain is believed to be of an alluivum-colluviums' origin, that is, partially transported by water and partially brought by gravity, and then deposited. King (1965) believes that the clay plain in eastern Sudan is a result of two processes: firstly degradational process, which is seen as an erosion of metamorphic rocks of the Basement Complex, and secondly aggradational process in which deposition takes place after regional wrapping associated with up lift. These soils are deep, have high clay content of the smectite clay mineral, dark in colour, with poor soil physical properties, alkaline, non saline, and with low nitrogen and organic matter content. Also these soils exhibit minimal horizon differentiation (A/C horizon) as a result of pedoturbation (churning) (Ahmad, 1983). Although these soils are considered among the most productive but some of their physical properties such as the limited available water, shrink and swell movement and deep cracking, and compaction still poses a problem (Duchaufour, 1982). The process of soil formation of these clays is several but they are predominated by argillipedoburation (Boul et al., 1980), that is, a pedo-genetic process which is generally known as self-mulching or churning. Blokhuis et al. (1964) stated that Sudan clays are generally dominated by smectites, associated with different amount of kaolinite. Bunting and Lea (1962) stated that the churning process usually precucles the defferntiation of horizons in the soils, and its internal pressure results in formation of polished and grooved surfaces (slickenside) of soil aggregates.

The objective of this study is to characterize the macro morphological features of Vertisols in semi arid climate, in Rahad Area, Eastern Sudan.

## MATERIALS AND METHODS

### Materials

The study area is located at the east boundary of the Rahad Agricultural Scheme. It is subtended by longitudes 33° 55′ and 34° 45′ E, and latitude 14° 15′ and 13° 23′ N (Figure 1). According to Van der Kevei (1976), the study area falls within the semiarid climatic zones. The weather of the area has three periods in the year: summer (Saif), autumn (Karief), and winter (Shita). The east-west isohyets pattern in Sudan is modified over the eastern clay plain by the presence of the Ethiopian highlands.

The rainy season is from June to October, where the bulk of rainfalls occur in July and August months. The long term (30 years) mean annual rainfall for Wad Medani, Sennar, Hawatta and Gadamabalyia are 84, 454, 505 and 568 mm, respectively. The locations of the mentioned meteorological stations are adjacent to the study area. The highest relative humidity occurs in August and the lowest in April. The soil temperature regime is ustic and moisture regime is isohyperthermic. The soil is classified as very fine, smectitic isohrperthemic, typic haplousters. The geological formation in the area is the Precambrian Basement Complex acts as a platform on which other geological formations rested. This Basement Complex is out crops in the study area at Qalat Arange range (Jebel Al Fau) and Buweida inselbergs (Jebel). The southern part of the study area has Umm Ruwaba Series which is reset on the Basement Complex. Superficial deposits of thick clay mantle speared over the flat plain where not exceeding 1% slopes. The clay plain slopes very gently from east to west at a general elevation of 420 to 440 m. The superficial deposits of clay in southern area, is originated from the Ethiopian plateau. The clay in northern area is originated from alluvium and colluviums deposits materials of Gadaref - Galabat ridge (Whiteman, 1971). The vegetation types in the survey area according to Harrison and Jackson, (1958) *Acacia Mellifera* (Kitter) thorn land alternating with tall grasses but the intensive cultivation removed the natural vegetation.

### Field survey methods

The soil profiles were excavated to a depth of 250 cm depth and were described according to "Guidelines for Soil Description" (FAO, 2006). Surface mulch was described for its depth. Calcium carbonate gray nodules on the surface were described on basis of abundance and sizes. The soil colour was determined by using soil Munsell charts, texture by using left hand fingers adding suitable water to crashed soil to work it. Soil structure was described on qualitative base. Soil consistence was described as dry, moist, and wet soil sample. Porosity was described on basis of abundance, size and type. Soil calcareousness checked by 10% HCl. Calcium carbonate was described on basis of abundance, size and type. Sub soil vertic features were described on basis of abundance, distinctness, and size. Soil boundary was described according to its depth, distinctness, and topography.

## RESULTS AND DISCUSSION

### Soil mulch

Mulch is the soft layer of medium to fine granular aggregates on Vertisols surface with variable thickness. The mulch thickness in the study area ranged from 0.5 to 5cm; this variability was observed to be correlated with cultivation density. Hunting (1966) observed that under the dense stand of sorghum grass the mulch is thin (1 cm), where under sparse grass vegetation or absent; the mulch is thick (5 cm). Other soil scientists related soil mulch thickness variation to climatic conditions, where it is thicker in dryer parts; than in wetter parts of eastern Sudan (Abdullah, 1989; Blokhuis, 1982; Jewitt et al., 1979). Buraymah (1977) noticed that in central clay plain of Sudan the surface mulch is thicker in soil with the light colour (dry conditions) than those of dark colour (wet conditions). In the past, the surface mulch was used in suborders division of Aquerts and usterts as grumaquerts and Grumusters.

### Cracking

The formation of these specific features are caused by a heavy texture, a dominance of swelling clay in the fine fraction and marked changes in moisture content (Hubble, 1984). Cracks open up in a polygons pattern with an average diameter of about 25 cm width and 80 cm length (Figures 2 and 3). These polygons were observed to be intensive in dry parts of the study area (Figure 3). The cracks were found throughout the study area; with variable widths ranging 2 to 7 cm (Figures 2 and 3), and depths ranging from 50 to 80 cm, according to the soil moisture content, and their depths are proportional to width. The depth frequency, size, and shape of the cracks are related to the differential moisture status at the cracking zone (Zein El Abedine and Robinson, 1971; Dudal and Eswaran, 1988). Usually cracks develop when the smectite clay (2:1 clay mineral) dries; and their width and depth associated with desiccation degree. Abdullah (1989) stated that the increasing pattern of cracking is a property of Vertisols in dry areas. The cracking phenomenon is one of the distinguishing characteristic of the Vertisols that governs many soil processes. This phenomenon influences soil

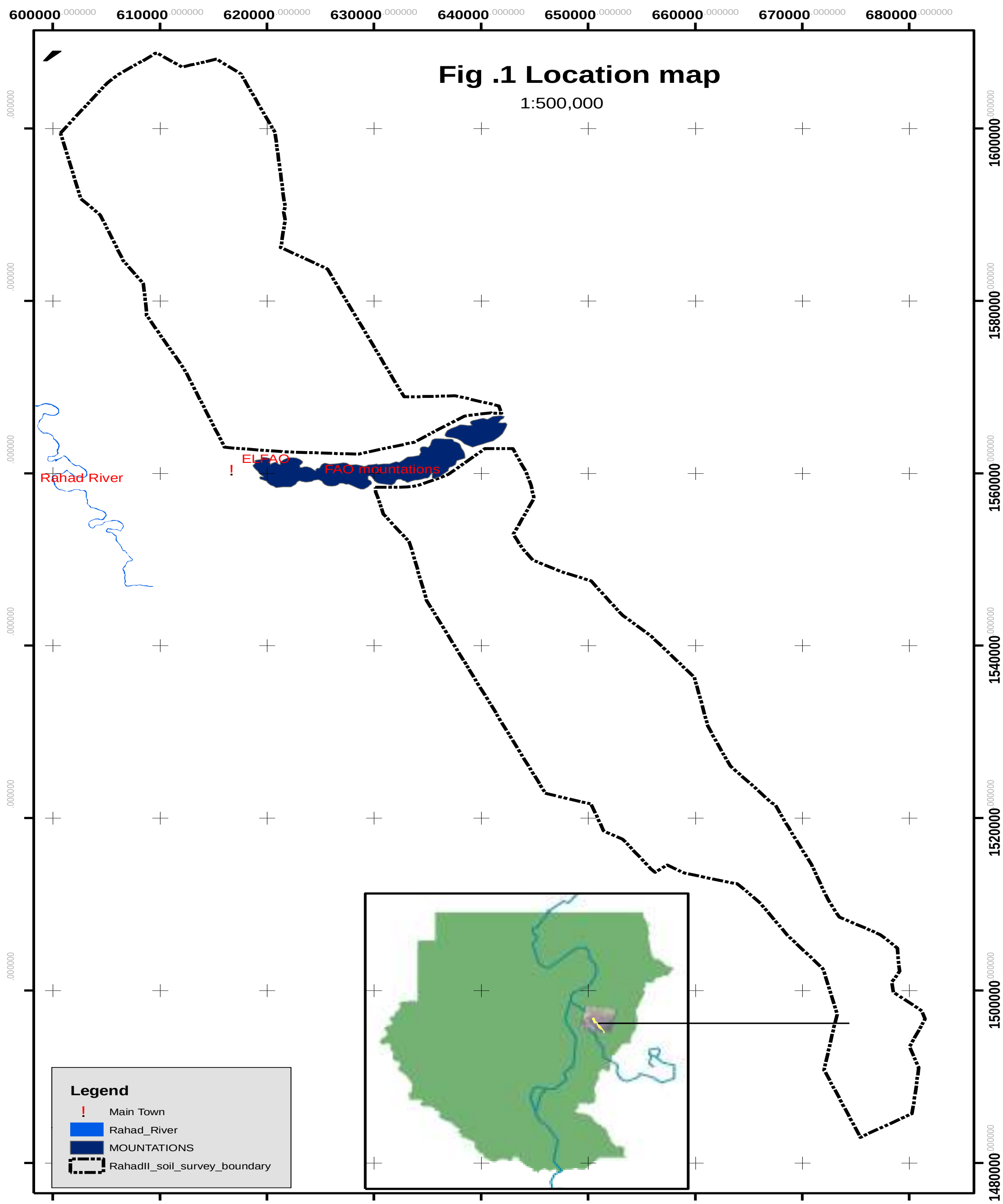


**Figure 1.** Location of the Rahad.

properties development and soil characteristics such as the formation of gilgai micro-relief, slickensides, and churning process. These cracks are beneficial to Vertisols at the beginning of the rainy season, but they have a negative effect on soil moisture content during the dry season. During the rainy season and before cracks sealed-off they literally engulf large water quantities into the soil body. When these cracks sealed-off water in cracks can moves laterally towards the dry areas of the polygons. However, during dry periods, especially summer time, the open cracks markedly reduce the soil moisture because they provide extra surfaces for evaporation of soil water. It was found that cracks may increase the actual evaporation surface four times from

**Figure 2.** Pronounced cracking pattern with wide width.

**Figure 3.** Intensive cracking pattern with small width.

the same soil area of non-cracking soils (Rai, 1964). Also, Rai (1964) reported that ploughing the cracking soil at early October or mid-October significantly reduces the evaporation from cracks in the central clay plain of Sudan. Generally, cracking of these soils is pronounced in cultivated areas and areas with sparsely vegetation cover. It is weakly developed in areas that have dense cover of grasses or bushes and shrubs.

## Soil colour

It is the most soil property commonly used by soil scientists to describe and differenciate soil horizons. Colour of the soil is an indicator for important soil characteristics, such as mineral composition, age, drainage, and soil processes within the profile. The dominant colour of the top soil layer (0 to 20 cm) in the study area are dark brown (10YR3/3) (≥ 50%), and very dark grayish brown (2.5Y 3/2) (30%). The brown (10YR 4/3) and the dark gray brown (2.5YR 4/2) soil colour are less dominant. The subsoil layers are darker than the top soil layers (20 to 180 cm). The underneath soil substratum colour are lighter and showed mottles with mixture of colours. The ultra mafic parent rocks of these soils have significant influence on soil colour in the study area. The top soil layer which is in direct contact with the sun rays, and the dry air may cause the colour to whiting.

The relatively darker colour of the subsoil layers may be due to the poor drainage conditions. Also the leashed organic matter from the top soil; coated the clay particles giving the darker soil colour. It was reported that the dark colour (low chroma) could be related to the strong impregnation of profile by organic matter during pedogenesis or to pro-long water logging (Ekinci et al., 2004). The substratum of the soil is an accumulation zone for the leached salts which has lighter colour. The colour of mottles at substratum may be attributed to the oxidation – reduction reaction of magnesium and ferrous oxides (Figure 7).

**Soil texture**

Soils texture is very fine clay (≥ 60%) throughout the study are; where the dominant clay mineral is smectite (2:1 layer silicate mineral). The clay content in the study area is high; with an average of 67%, maximum of 81%, and minimum of 59%.The previous mineralogical studies in eastern Sudan showed that the soils were dominated by smectitic clay; with minor amount of kaolin group (Khalil, 1986; Dahab, 1983). The smectitic clay mineral swelling and shrinkage upon wetting and drying, leads to soil cracking formation. The texture affects soil productivity is perhaps the basic factor that determines the moisture characteristics of the soil (Lal, 1978). The variation in clay content within the profile was lower in the surface horizon than that of the subsurface horizon. This may be attributed to the dust storm blown from the more arid part of Sudan and probably from further north, were seen to deposited coarse soil fractions on soil surface. Also the running seasonal streams and small water channels that traverse the area during the rainy season carried away the finer clayey materials. Soil degradation study in Rahad area (Meheissi and Adam, 1998) showed that the silt fraction in the percent noticeably increased and clay percent decreased. The reason of this increased may be attributed to prevailing aridity. Also high aridity may cause clay particles to fussed together forming pseudo-silt particles which increase the silt percent over clay percent. There are no clay skins observed in this study, and this was confirmed by Hunting (1966) previous study in the area. The variation in clay content between the profiles in the study area may be attributed to the position of the soil profile site. Soil profiles on concave or depressions sites their clay content may be more than that located on convex sites. It was reported that in many studies and researches the clay content generally decreased as one moved from wetter to drier part in eastern region of Sudan (Abdalla, 1989, Dahab, 1983; Meheiss and Adam, 1998).

**Soil structure**

It was observed that all soil profiles in the study area have a similar soil structure development in grade, type and size (Figure 4). The soil structure in Vertisols has typical sequences of degradation by increasing soil depth. On the top layer is strong or moderate, the subsoil structure is weak, and underneath is massive especially after the cracking zone. The top horizons of profiles have strong, medium and coarse granular structures, due to high clay content (Dengiz et.al, 2012). The study showed that the top soil horizon has moderate, fine and medium angular and subangular structure. The subsurface soil horizon has weak; medium, coarse, and very coarse, subangular structure. The soil horizon after cracking zone has massive structure. The cracking (swelling and shrinking) process has a significant role on soil structure formation in Vertisols. Hunting (1966) found that the structure of the intermediate layers is weakly developed with fine and medium sub angular blocky structure. The structure below the cracking zone is massive throughout the soil profiles. However, the vertic features in Vertisols controlled most of its soil properties; especially structure. Also the rainfall, relief, and vegetation cover affect soil structure. Soil profiles that lake cracking or with faint cracks their structure is weakly developed (Figure 5). It is worth mentioning that soil structure in eastern Sudan was much deteriorated due to the introduction of machinery in the mechanized agricultural rain fed schemes. Another important factor cause’s soil structure deterioration is the misuse of machinery for tillage and cultivation when the soil moisture was not optimal for ploughing (Mahmoud, 1985; Bolkhuis, 1982; and Buraymah, 1977).in grade, type, and size (Figure 3). The top soil structure (0 to 20 cm) grade is moderate in more than 95% of the soil profiles. Management of Vertisols is constraining the profitable agricultural production in study. The poor soil structure prevents Vertisols from agricultural as well as engineering use and makes management difficult (Dinka et al., 2011).

**Soil consistence**

Soil consistence is the ability of the soil to resist rapture or deformation. The top soil layer is hard when dry; and friable when moist, very sticky and very plastic when wet. The subsoil when dry is very hard, friable when wet. Upon wetting these soil is very sticky and very plastic. Hunting (1966) in their soil survey of the study area observed that soil consistence is related to soil structure down the profile. Vertisols consistence nature makes workability difficult. The rain fed cultivation in eastern is faced by the critical period for the optimum soil moisture content for land preparation. The cultivation of Vertisols when too dry or too wet may result in poor tilt due to cloddy or puddle structure. Tillage is hindered by stickiness when the soil is wet and hardness when it is dry. The susceptibility of Vertisols to water logging may be the single most important factor that reduces the

**Figure 4.** Moderate blocky structure top, weak beneath, and massive below the cracking zone.


**Figure 5.** Weak soil structure due to poor cracking pattern.

actual growing period.

### Soil boundary

The horizon boundary in Vertisols profile can be detected by some soil properties as: soil structure, soil colour, and the amount of accumulated salts (calcium carbonates and gypsum). Generally, the top horizon boundary can easily been detected but the subsoil ones are difficult to be recognized. The study showed that a clear wavy horizon boundary in the top horizon, the second horizon boundary is gradual wavy. The lower depth of soil profile showed diffuse soil boundary.

### Calcareous

The calcareous of the soil is usually checked in the field by treating the soil matrix with 10% HCl. The degree of violence of the effervescence is employed to estimate the quantity of free calcium carbonate of the soil matrix. In this study, the effervescence was moderate to slight throughout the soil profile matrix. The parent rocks are mafic rocks which often contain calcium-rich varieties of plagioclase feldspar.

### Subsoil vertic features

These are features at subsoil layers formed by the action of swelling and shrinking processes as a result of wetting drying cycles. The process that formed these vertic features is the dominated soil forming process and known as agrillipedoburation (Boul et al., 1980). Pedoturbation (churning) is a process which homogenizes the soil profile due to the infilling of the cracks by surficial material during dry season. The process in Vertisols is also called self-mulching or self-swallowing. The process is a pedo-genetic which generally had known as self-mulching or churning. Parallelepipedal structural aggregates are found in a horizontal layer of about 10 cm thickness, which normally appear in the soil horizon between 40 and 50 mm soil depth. Slickenside has their long axis tilted 10 to 60 degrees from the horizontal usually appears below 50 cm and their size pronouncedly increased by soil depth (Figure 6). Slickenside's had an orthorhombic form, 5 to 10 cm long along their long axis; and smooth or striated ped faces. Slickenside's development at maximum; in deeper soil layers, because the net pressure is much greater than the shear strength of the material and soil movement occurs with swelling.

### Soil porosity

Soil porosity is an important characteristic of the soil for plant growth and crop production. Porosity in the soil allows the soil solutes movement, aeration, and gas diffusion. The pores in the soil profile mostly very fine, fine (micropore), and few medium (mesopore). The coarse pores (macropore) are usually found at deeper moist subsoil where biological activity present. The micropores are too small for plant to use without great difficulty; and water associated with is usually adsorbed on the clay molecules surfaces. The water held by micropores is important to microbe's activity creating an anaerobic moist condition. Mesopores are known to be the storage pores because of their ability to store water that can be easily used by plants. Macropores are too large to have significant capillary forces, and they formed by soil cracking, and biological activity. However, the poor hydraulic conductivity, permeability, and infiltration are generally poor in Vertisols because of their pores types. However, the pores have critical impact on soil water other solutes movement within the soil profile. Compacted layers which is usually formed under cultivation; has poor porosity decreased the infiltration and soil permeability. The high percent of fine clay particles resulted in poor porosity which badly affected soil solution movement, oxygen and $CO_2$ diffusion, and soil drainage condition. The poor porosity in Vertisols during rains water cannot penetrate in the soil and this causes water run- off that induces water erosion for the surface soil plant nutrients.

### Calcium carbonate gray nodules on the soil surface

The calcium carbonates ($CaCO_3$) gray nodules are commonly found on the surface as gray nodules. A number of gray nodules present on the surface are common, hard, fine, medium, and coarse. Their shape is smooth spherical and rounded shape. The gray nodules which present on the surface some authors suggested that their formation was inside the soil and then migrated up in the self-mulching process (Hunting, 1966). Worrall (1959) has suggested that the dark coloured concretions are formed as light coloured ones, small quantities of manganese and other salts present as small dark specks in the concretion migrate outwards and formed a hard outer coating over the calcium carbonate ($CaCO_3$).

### Calcium carbonates within soil profile

Calcium carbonates ($CaCO_3$) occurred in variable amounts and a wide variety of forms, size, and shape throughout Vertisols soil profiles. On the top soil layer, the amount of $CaCO_3$ is few and mostly fine and medium hard concretions. The $CaCO_3$ amount increase with depth, at cracks bottom their amount is common and mostly hard concretions and soft whitish segregates (Figure 7). Water that entered by cracks accumulated at

**Figure 6.** Slickenside at 80 cm soil depth.

**Figure 7.** Accumulation whitish segregates of $CaCO_3$ in the profile after the cracking zone.

the bottom of the cracks and most of the salts precipitated. The $CaCO_3$ at substratum are hard; common and abundant with coarser sizes and have mixture of colors (at the bottom of the soil profile in Figure 5). The effect of pedoturbation on nodules shape and the cracks on $CaCO_3$ within the soil profile is clear. In stable soils they generally have a diffuse and irregular outline, whereas disorthic nodules indicate the effect of some pedoturbation (Wieder and Yaalon, 1974). Disorthic nodules are typical of Vertisols, shrinking and swelling of clay minerals leading to the displacement of the nodules.

## CONCLUSIONS

The characterization of Vertisols indicated that macro morphological soil properties were affect by soil forming factors as well as soil processes. The parent material and climatic conditions in the area resulted in formation of the swelling shrinking clay mineral. The soil processes in Vertisols were governed by the vertic characteristics of these soils. The horizon differentiations are minimal due to churning process (pedoturbation). The cracking pattern of these soils has an effect soil structure types. The poor porosity due to high amount of fine clay particles, has pronounced effect on many soil processes, such as soil solution movement, oxygen and $CO_2$ diffusion, and soil drainage

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