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THESIS

**THE DISTRIBUTION TRENDS OF SALT AFFECTED SOILS
IN NORTHEAST PLATEAU BASINS, THAILAND**

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**A Thesis Submitted in Partial Fulfillment of
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The purposes of the study on the distribution trends of salt affected soils in Northeast Plateau Basins, Thailand were to determine the soil characteristics and distribution and to establish relationships between environmental conditions and the distribution of these soils under a tropical savanna climate. Twenty one salt affected soil profiles were selected from highly to slightly salt affected areas. Methods of study included soil pedon analysis and laboratory analysis of soil samples for their physical, chemical, mineralogical and micromorphological properties. Geographic information system technique as overlaying was used to analyze the distribution trends of salt affected soils and the relationship between these soils and spatial factors.

Results of the study revealed that all soils have moderately to highly developed profiles. They included seventeen saline-sodic Natraqualfs, two sodic Natraqualfs, a saline Endoaqualf and a saline Kandiaqualf. Soils have developed from transported materials as alluvium and/or wash deposits and residuum derived from the weathered salt bearing sedimentary bedrock on low terraces and some of them on erosional plains and floodplain with flat to undulating surface. Characteristics of this residuum layer indicate that it is the main source of salts in these soils. Most soils have mixed mineralogy and kaolinite is the dominant mineral in the clay fraction. Aggregate stability of these salt affected kaolinitic soils measured by the wet sieving method ranges from 3-91 %. The soil property that is most strongly correlated with aggregate stability is pH ($r = -0.84$) followed by exchangeable potassium ($r = +0.75$), cation exchange capacity ($r = +0.73$), clay content ($r = +0.72$), extractable acidity ($r = +0.66$) and organic matter ($r = +0.66$). However, no significant relationships exist between aggregate stability and ESP, SAR or EC. Multivariate stepwise regression analyses indicated that aggregate stability of these mostly saline-sodic soils was well predicted by a combination of soil pH and clay content. The presence of small amounts of smectite and illite may have reduced the stability of the dominantly kaolinitic soil aggregates.

Salt content in the profiles (depth 2 m) ranges from 241 to 3115 ton ha⁻¹. Multivariate stepwise regression analyses indicated that the salt content of these soils was well predicted ($R^2 = 0.73$) by a combination of rainfall, rock type, parent material, surface slope and land use. The high salt contents in the soil profiles mostly occur in the western edge of the basin where shallow residual layer is present with rainfall less than 1100 mm y⁻¹. Rainfall is a major controlling factor for the distribution of these soils on the western rim of the basin which is also controlled by rock structure. The factors that affect the distribution of salt affected soils are high evaporation and land management. Their distribution tends to be widespread in the west of the basin where evaporation is high with the presence of a shallow residual layer towards the northeast of the basin and tends to decrease in the east of the basin where rainfall increases. Salt affected areas are cut off at 1600 mm y⁻¹ of rainfall.

Student's signature

Thesis Advisor's signature

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THE DISTRIBUTION TRENDS OF SALT AFFECTED SOILS IN NORTHEAST PLATEAU BASINS, THAILAND

INTRODUCTION

Salt affected soils contain considerable amounts of soluble salts that have adverse affects on plant growth (Feng *et al.*, 2003; Chhabra, 2005). They generally have a dense subsurface horizon with high exchangeable sodium or a secondary enrichment of soluble salt (Seelig and Richardson, 1994; Soil Survey Staff, 2006; Lebedeva *et al*, 2009). Sodium salts dominate in many salt affected soils but salts of calcium, magnesium and iron also occur in specific locations (Rengasamy, 2006) and sodium salts also pose a particular problem as the positively charged sodium ions strongly repel each other, contributing to poor soil structural stability (Nelson and Oades, 1998). Hence, soil sodicity adversely affects soil physical conditions (Ruiz-Vera and Wu, 2006).

Saline soils occur under various conditions of soil, climate and physiography (FAO, 2006). Salt affected soils are common in arid and semi-arid regions because the amount of rainfall is not sufficient for leaching and removal of salts and potential evaporation is greater than atmospheric precipitation (Fullen and Catt, 2004; Luedeling *et al.*, 2005). However, in some other regions, the climate and salt mobility produce saline water and soil seasonally. The warm temperate to subtropical seasonal climates in general have sufficient rainfall for dryland cropping but irrigation is used to produce crops in the dry season. One again, rainfall is not sufficient for leaching of salt (Keren, 2000; Corwin *et al.*, 2003). For a monsoonal tropical zone, the drier climates have greater salinization problems but some regions within the wetter climates also have serious problems because of inherently saline substrates (Ghassemi *et al.*, 1995; Ali, 2003; Furquim *et al.*, 2009).

Salt affected soils are problem soils in Thailand (Kheoruenromne, 1991). They mostly occur in the Northeast Plateau Basins, Central Plain and Coastal areas. Soil salinization in Northeast Plateau, Thailand could be caused by both natural phenomena and human activities. Salt affected soils occur as bare saline patches in lowland paddy soils (Ghassemi *et al.*, 1995). The salt distribution map of Northeast Plateau, Thailand was based on LANDSAT-5 TM data in combination with field observations (Department of Land Development, 2003). Salinity levels were defined by the percentage of surface salt crust in the dry season (Arunin, 1998). The areas covered by more than 50, 50-10 and 10-1 percent salt crust were described as highly, moderately and slightly salt affected respectively.

Salt affected areas occupy about 17 percent of the Northeast Plateau and are extensive in the Khorat Basin (Sukchan and Yamamoto, 2003). The source of salt is the Mahasarakham formation which consists of salt bearing sandstones, siltstones and shale (Geological Survey Division Staff, 1985; Dheeradilok, 1993). Deforestation, construction of reservoirs, salt making and irrigation were cited as activities causing the spread of salinization in this region (Sukchan and Yamamoto, 2003). Most studies on salt affected soils in the Northeast Plateau emphasized their profile properties and salinity levels (Vichiansinpa, 1992; Kohyama and Subharam, 1993; Promdecha, 2001; Wongpokhom, 2007). Few studies have considered the specific conditions responsible for inducing salt accumulation in the soils or identified factors affecting their distribution. Therefore, the study on environmental conditions of salt affected soil distribution is important for providing an understanding of causes and the mechanism in pedogenesis of these soils that should be useful for effective land use planning and land utilization in this region

This study aims at differentiating features and properties of salt affected soils by investigating their morphological, micromorphological, physical, chemical and mineralogical properties. These data will provide a basic understanding of the formation and factors affecting the distribution of salt affected soils in Northeast Plateau Basins, Thailand.

OBJECTIVES

This study was carried out on salt affected soils in the Northeast Plateau Basins, Thailand:

1. To determine morphological, physical, chemical and mineralogical properties of salt affected soils.
2. To establish relationship between environmental conditions and salt affected soils.
3. To determine specific properties of salt affected soils exhibiting sodicity.

Hypothesis

Various sets of environmental conditions under a tropical savanna climate affect the distribution and sodicity of salt affected soils in Northeast Plateau Basins, Thailand.

LITERATURE REVIEW

Nature of Salt Affected Soils

Definition

Salt affected soils are soils that contain considerable amounts of soluble salt affecting plant growth (Feng *et al.*, 2003; Chhabra, 2005). Salts more soluble than gypsum are called *soluble salt* (van Breemen and Buurman, 2002). Most soluble salts in soils are composed of the cations sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) and the anions chloride (Cl^-), sulfate (SO_4^{2-}) and bicarbonate (HCO_3^-). Relatively smaller quantities of potassium (K^+), ammonium (NH_4^+), nitrate (NO_3^-) and carbonate (CO_3^{2-}) are also included (Gardiner and Miller, 2004). The salts may be formed during the weathering of rocks and minerals or brought into the soils through rainfall and irrigation (Brady and Weil, 2007). Salt accumulation in soil causes soil salinity and sodicity, affecting soil properties and plant growth (Keren, 2000; Levy, 2000).

Soils Salinity and Sodicity

Salinity and sodicity are separate and unique descriptions of impacts of soluble salts on soils. Soil salinity refers to the state of accumulation of the soluble salts in the soil or the salt content of the soil that is too high for satisfactory crop production. Soil sodicity represents the relative predominance of exchangeable sodium compared to other exchangeable cations, chiefly calcium, magnesium, potassium, hydrogen and aluminium (van de Graaff and Patterson, 2001). Sodium, as sodium chloride (NaCl), is one of the main salt species in saline soils or saline water, while many other salts may also be present in highly variable amounts in different landscapes. Sodium sulfate, calcium sulfate (gypsum), calcium chloride, magnesium chloride and sodium bicarbonate may be present in acidic, neutral and alkaline soils in different proportions. Most of the sodium in salt affected soils is in the form of

soluble salts which can be easily dissolved and moved in soil water. Sodicity is caused by sodium attached to clay in soil (Rangasamy and Walters, 1994).

Salinity

Soil salinity is a characteristic of soils relating to their content of water-soluble salts (Charman and Murphy, 2000). Typically inorganic salts are crystalline ionic products that dissociate in water to form positively charged cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Al^{3+} , Cu^{2+} , Zn^{2+} , Fe^{2+}) and negatively charged anions (Cl^- , NO_3^- , PO_4^{3-} , SO_4^{2-} , CO_3^{2-} , HCO_3^-). The soluble salts dissociate in water to release cations and anions that can conduct an electric current. Thus, the simple measurement of how much current an aqueous solution will carry can be related directly to the amount (concentration) of salt present. Salinity can be determined by measuring the electrical conductivity of a solution extracted from a water-saturated soil paste (Friedman, 2005).

Sodicity.

There are two important parameters that are generally used to evaluate the sodium status which are exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR). The ESP is the amount of sodium held in exchangeable form on the soil's cation exchange complex expressed as a percentage of the total cation exchange capacity (CEC). The ESP identifies the proportion of adsorbed sodium in the exchange complex of soil and is defined as:

$$\text{ESP} = \frac{\text{Exchangeable sodium, cmol kg}^{-1}}{\text{Cation exchange capacity, cmol kg}^{-1}} \times 100$$

Alternatively, the proportion of exchangeable sodium relative to summation of exchangeable cations may be calculated to provide the exchangeable sodium percentage (ESP) for the soil. This simple calculation (units of %) is used to indicate the likely effects that a soil may experience with respect to structural stability, because Na^+ ions favor dispersion and Ca^{2+} and Mg^{2+} favor flocculation (van de Graaff and Patterson, 2001). Sodicity is not the only factor involved in clay

dispersibility. Clays with a given sodicity are more dispersible at a high pH than at a low one (McBride, 1994).

The SAR is a second more easily measured property that is becoming even more widely used than ESP. The SAR gives information on the comparative concentration of Na^+ , Ca^{2+} and Mg^{2+} in soil solution which is calculated as:

$$\text{SAR} = \frac{[\text{Na}^+]}{([\text{Ca}^{2+}] + [\text{Mg}^{2+}]/2)^{1/2}}$$

Where $[\text{Na}^+]$, $[\text{Ca}^{2+}]$ and $[\text{Mg}^{2+}]$ are the concentrations in mmol L^{-1} of the sodium, calcium and magnesium in soil solution (Levy, 2000; Brady and Weil, 2007).

Classes of Salt Affected Soils

Salt affected soils are classified into three groups which are saline, sodic and saline-sodic soils. The principle criteria used to classify them are: salinity of soil saturation extract as determined by the electrical conductivity (EC) at 25°C, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and the pH of the saturation extract (U.S. Salinity Laboratory Staff, 1954; National Soil Survey Center, 1996; Soil Survey Staff, 2006).

Saline soils

Soils that contain a concentration of soluble salts sufficient to interfere with plant growth are saline soils. The electrical conductivity (EC) of a saturation extract of the soil solution is more than 4 dS m^{-1} , or 2 dS m^{-1} for some salt-sensitive fruit and vegetable crops. The sodium ion concentration in the soil solution of saline soils may be somewhat higher than that of calcium and magnesium ions due to the presence of soluble salts that commonly high in sodium. However, because of the greater affinity of the colloids for divalent cations, such as calcium and magnesium ions, the sodium adsorption ratio (SAR) is less than 13, exchangeable sodium percentage (ESP) is less

than 15. The pH value is usually less than 8.5. The salts are commonly brought to the soil surface by evaporating waters, creating a white crust, which accounts for the name white alkali or Solonchak soils (Singer and Munns, 2002, FAO, 2006).

Sodic soils

Soils that have low levels of neutral soluble salts but are high in exchangeable sodium are sodic soils. Their electrical conductivity (EC) of a saturation extract is less than 4 dS m^{-1} . Their ESP values are above 15, SAR values are above 13 suggesting a comparatively high level of sodium on the exchange complex. The pH values of sodic soils exceed 8.5, rising to 10 or higher in some soils due to hydrolysis of sodium carbonate (Brady and Weil, 2007).

Saline-sodic soils

Soils that have characteristics of saline and sodic soils are saline-sodic soils. The soils contain both sufficient soluble salt and exchangeable sodium ion to adversely affect plant growth. The electrical conductivity (EC) value of a saturation extract of the soil solution is more than 4 dS m^{-1} , ESP is greater than 15, SAR is greater than 13 and the pH value of a saturation extract is 8.5 or less. Because of the extreme alkalinity resulting from the high sodium content, the surface of sodic soils often is discolored by the dispersed humus that can be carried upward by the capillary water and deposited when it evaporates. Hence, the name black alkali or Solonetz has been used to describe these soils. Sometimes they are located in the small areas called slick spots (Schaetzl and Anderson, 2005).

Most saline and saline sodic soils have a pH value of a saturation extract less than 8.5 and the pH of sodic soil is more than 8.5. The high pH is largely due to the hydrolysis of sodium carbonate (Brady and Weil, 2007). Extremely high pH (greater than 8.5) occurs in sodic soils when soda (NaHCO_3) or sodium carbonate (NaCO_3) is present. Sodium-clay, bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) react with water to liberate hydroxyl (OH^-) ions that cause high pH (Seelig, 2000).

Diagnostic Horizons of Salt Affected Soils

According to Soil Taxonomy (Soil Survey Staff, 2006), salt affected soils generally have a natric horizon or salic horizon in their profiles.

Natric horizon

A natric horizon is approximately equal to the horizons in a soil to which the symbol Btn is assigned. This horizon is a special kind of argillic horizon and is a dense horizon (FAO, 2006). The following definition of natric horizon is described in Soil Survey Staff (2006).

The natric horizon has, in addition to the properties of the argillic horizon:

1) Either:

- a. Columns or prisms in some part (generally the upper part), which may break to blocks; *or*
- b. Both blocky structure and eluvial materials, which contain uncoated silt or sand grains and extend more than 2.5 cm into the horizon; *and*

2) Either:

- a. An exchangeable sodium percentage (ESP) of 15 percent or more (or a sodium adsorption ratio [SAR] of 13 or more) in one or more horizons within 40 cm of its upper boundary; *or*
- b. More exchangeable magnesium plus sodium than calcium plus exchange acidity (at pH 8.2) in one or more horizons within 40 cm of its upper boundary if the ESP is 15 or more (or the SAR is 13 or more) in one or more horizons within 200 cm of the mineral soil surface.

Salic horizon

Salic horizon is approximately equivalent to horizons given subscript z. It is a horizon with a significant accumulation of salt more soluble than gypsum in cold water, and formed by salinization. A common salt is halite, the crystalline form of sodium chloride. In some areas, soluble sulfate may also accumulate with crystalline forms such as thernadite, hexahydrite, epsomite and mirabilite. The following definition of salic horizon is described in Soil Survey Staff (2006).

A salic horizon is 15 cm or more thick and has, for 90 consecutive days or more in normal years:

- 1) An electrical conductivity (EC) equal to or greater than 30 dS m^{-1} in the water extracted from a saturated paste; *and*
- 2) A product of the EC, in dS m^{-1} , and thickness, in cm, equal to 900 or more.

Nature of the Environment Inducing the Formation of Salt Affected Soil

There are two major factors that favor salt accumulation in soils. One is parent material as a source of salt and another is the water regime associated with climate and topography (Dan and Yaalon, 1982; Berger and Cooke, 1997; Gerrard, 2000; Schaetzl and Anderson, 2005).

Source of Salt

The source of salt is an important consideration in the formation of these soils. The major sources of soluble salts in these soils are *in situ* weathering, sedimentary rocks (fossil salts), atmospheric deposition, saline water bodies (cyclic salts) and anthropogenic activities (secondary salinization sources) (Essington, 2004). However, weathering of rocks and minerals is the ultimate primary source of all soluble salts present in the soil (Berger and Cooke, 1997; van Breeman and Buurman, 2002).

Salt can be formed during weathering of the parent material. Under humid conditions, salts commonly percolate through the soil and are transported to the sea by streams and rivers. Therefore, inland salt affected soils are rarely formed in humid areas. Under arid and semi-arid condition these weathering products accumulate *in situ* and result in the development of salinity or alkalinity. Shallow groundwater is another important source of salt. With the high potential evaporation rates in drylands, shallow groundwater can rise by capillary action through soil pores, particularly in fine-textured soils. The water evaporates at the surface and thus leaves behind salt residues (Gerrard, 1992). In addition, salt can be brought into soils by irrigation water. When waterlogging is present at some depth the water evaporates again and the salt transported with the water from elsewhere is left behind (Chhabra, 1996; Fullen and Catt, 2004).

Water Regime

The water regime is vitally important in salt affected soil genesis because percolating water dissoles minerals and transports ions, colloids and metalorganic complex, including soluble salts downward in the soil profile (Schaetzl and Anderson, 2005). The amount of water in a soil is related to the climatic conditions over the soil and the position of a soil in the landscape influences leaching and salt accumulation (Yair, 1990; Buol *et al.*, 2003). The distribution of salts in soil landscapes is controlled primarily by subsurface hydrology and the balance between evaporation and leaching (Chadwick and Graham, 2000). The salts also tend to accumulate according to their mobility (Berger and Cooke, 1997). Therefore, understanding the water regime of a soil is vital to interpreting its development. Drainage is an important component of that water regime which relates to the rapidity and completeness of removal of water added to a soil. Internal drainage is impacted by permeability and water table relations. External drainage is largely a function of slope configuration (Schaetzl and Anderson, 2005).

1. Climate and Hydrology

Climate has an effect on salt affected soil formation. It acts directly on the moisture and temperature regimes of the soils. And it acts indirectly through its role in controlling the processes of erosion, transport and deposition. The amount of moisture influences weathering and leaching. One of the major ways in which climate influence soil processes is through the soil water balance (Gerrard, 2000).

Salt affected soils are common under arid, semi-arid and sub-humid conditions, but they can also occur locally in more humid climates. Under such conditions, the amount of rainfall is not sufficient for leaching and removal of soluble salts in the soil (Brady and Weil, 2007; Essington, 2004). Under hyperarid conditions and at low temperatures, evaporites of calcium and magnesium chlorides, nitrates and other soluble salts can accumulate in soils (Dan *et al.*, 1982). Chhabra (1996) stated that, normally, salt accumulation does not occur in areas that get more than 1000 mm year⁻¹ rainfall. Similarly, a high supply of rainwater more than 1200 mm year⁻¹ rain during at least about 9 months per year is essential to promote sufficient leaching activity during the wet season (Aleva, 1994).

Salt affected soils can be found in the regions that are seasonally dry (Evans and Turnbull, 1982). In tropical climates, atmospheric precipitation is received during rainy seasons. A part of the rainwater is lost to atmosphere by evaporation. A significant proportion of rainwater percolates vertically downwards in the unsaturated zone of the soil and joins the groundwater in the saturated zone of the soil profile. In the dry season, only evaporation and lateral flow are operative. The lateral transport of ions in solution takes place in groundwater with lateral circulation and accumulation in the lowlands, where the water table is shallow enough to supply water and ions to the evaporation front (Tardy, 1997). In the warm temperate to subtropical seasonal climates, in general, sufficient rainfall for dryland cropping can induce salt accumulation in the soils. The monsoonal tropical climate and the drier climates may experience soil salinization problems but some regions within wetter

climates also have serious problems because of the inherent saline substrates (Ghassemi *et al.*, 1995).

2. Topography

Salt affected soils generally occur on landscape positions where the water table is shallow and where evaporation exceeds infiltrations. Kianian (2006) studied the toposequence of salt affected soils for highly calcareous parent material and semi-arid conditions of southern Iran and found that saline soil had been formed on floodplain with shallow groundwater and sodic soils on the low terraces with moderately deep groundwater. A study of soil toposequences in humid areas reveals that soils on the upper part of a slope are usually well-drained and display elluvial conditions (Yair, 1990). In addition, in humid areas, most wetland depressions are groundwater discharge areas where groundwater emerges to become surface water. The water table is mounded under topographic highs, and is close to the surface beneath depressions. Thus water is moved from recharge (upland) areas to the discharge areas, keeping them wet even during climatically dry intervals. Capillary flow of water and dissolved substrates from the shallow water table can lead to the formation of salt affected soils in these low spots (Miller *et al.*, 1985; Mausbach and Richardson, 1994). Therefore, salt affected soils mostly occur on the edges of closed depressions or valley sides of the landscape (Caballero *et al.*, 2001; Chernousenko, 2006; Rengasamy, 2006). This may indicate that topography is related to water table level which influences leaching and salt accumulation (Yair, 1990; Corwin and Lesch, 2005a, b).

Generally, they occur in soils that have medium to high development such as Inceptisols, Mollisols and Alfisols. However, dryland salt affected soils and coastal salt affected soils occur in Aridisols and Entisols (Seelig *et al.*, 1990; Heck and Mermut, 1992; Suddhiprakarn and Kheoruenromne, 1998; Kianian, 2006; Soil Survey Staff, 2006).

Human Role in the Development of Soil Salinity

Agricultural land has become salt affected area because of several faulty human activities such as land clearing and mismanagement of irrigation. Most salt-affected lands have resulted from forest clearance that changes the hydrologic balance of the soil (Hatton *et al.*, 2003; Pannell and Ewing, 2006). For example, within the south-west agricultural region of Western Australia, 1.8 million ha of land have been affected due to the replacement of deep-rooted native vegetation with shallow-rooted agricultural crops (Nulsen and McConnell, 2002). Capillary upflow from shallow groundwater is a significant contributor of soil salinization in irrigated areas and is highly dependent on water table position and salinity (Northey *et al.*, 2006). Surface irrigation methods which are used very widely have a low efficiency. In an irrigated area, where the natural or artificial drainage is not adequate, percolating water gradually accumulates and raises the water table to within a few meters of land surface. Consequently, after several years of using an irrigation system without adequate drainage facilities, the groundwater approaches the surface. Once the water table is close to the soil surface, appreciable upward movement of groundwater due to evaporation from the soil surface takes place and results in the accumulation of salt in the root zone (Ghassemi *et al.*, 1995). In addition, construction of road, dam, canals and bunds can block the natural surface drainage of the area which leads to waterlogging, rise in water table and ultimately salinization (Chhabra, 1996).

Formation of Salt Affected Soils

Formation of salt affected soils is controlled by the processes of accumulation and removal of salts comprising the following stages: salinization, desalinization, alkalization, dealkalization and solodization (Buol *et al.*, 2003; Schaetzl and Anderson, 2005).

Salinization

The accumulation of soluble salts such as chlorides, sulfates, and bicarbonates of sodium, calcium, magnesium and potassium in the soil is often manifested as whitish salt accumulations on the soil surface. Soils undergoing salinization may develop a salic horizon (Soil Survey Staff, 2006). Salt accumulation is preferential in depressions in soil high in clay and with low permeability and with reduced leaching. The result of this process is a saline soil or Solonchak. Saline soils tend to be well flocculated due to the high salt concentration of soil solution and the presence of some divalent cations (Ca, Mg). Salinization occurs in soils that favor discharge (evapotranspiration loss) over leaching. Not all soils with a water balance favoring discharge are saline soils (Buol *et al.*, 2003; Schaetzl and Anderson, 2005).

Desalinization

The removal of soluble salts by leaching from soil horizons or total soil profiles may possibly be due to a change in climate or the surface or subsurface hydrology. This process is active after salinization and important for the development of saline-sodic soil. In this second stage of saline soil genesis, salts are leached but sodium ions still remain on the exchange complex (White, 1978; Buol *et al.*, 2003). Thus, accompanying desalinization is the alkalization of the soil (Schaetzl and Anderson, 2005).

Alkalization

This process involves the accumulation of sodium ions on the exchange sites of clay and organic matter with much dispersion of clay (Buol *et al.*, 2003). Groundwater discharge may lead to the development of sodic soils as sodium salts are concentrated in the soil. The soluble sodium salts are highly concentrated in the soil profile. As the soil solution becomes more concentrated in sodium, the percentage of sodium on the exchange complex also increases. Eventually there is enough exchangeable sodium to cause dispersion of clay. Organic matter is also dispersed,

giving the soil a dark color. The result of this process is the sodic soil (Franzer *et al.*, 1994; Buol *et al.*, 2003; Schaetzl and Anderson, 2005).

Dealkalization

The removal of sodium ions from the exchange sites. This is often accomplished by displacement of the exchangeable Na by Ca and removal of Na by leaching (Buol *et al.*, 2003). The upper part of soil profile may become sandier and more acidic while the unleached lower part of soil profile retains sodium (Schaetzl and Anderson, 2005). With continued dealkalization, the solodization process occurs.

Solodization

This process refers to the removal of sodium ions from the exchange complex due to continued leaching of the soil profile. Hydrolysis becomes a dominant process. The sodium on the exchange sites is replaced by hydrogen (Buol *et al.*, 2003). The soil becomes more acidic (Fanning and Fanning, 1989). A change in climate such increased rainfall further leaches the sodium ions from the exchange complex. This can also be caused by irrigation and snowmelt accumulations in low-lying areas over time (Henri, 1999). Solodization is inhibited in extremely dry climates or where shallow bedrock impedes leaching (Schaetzl and Anderson, 2005).

Characteristics of Salt Affected Soils

Morphology

The surface of salt affected soil generally has a crust, bare surface and the areas are left idle. Under extreme specific climate conditions (low rainfall and high evaporation), salts which are present in the soil solution precipitate at the soil surface in various forms such as white efflorescence, salt crusts, non-aggregated brown powder, black salt deposits and evaporative salt crystals. Normally, saline and saline-sodic soils have salt crust in the surface soil. Sodic soils have the flocculation or

dispersion of clay minerals and organic matter and black color. Halophytic plants are commonly found in these areas (FAO, 2000; Fernandez-Buces *et al.*, 2006).

The major morphological properties found in salt affected soils include the accumulation of soluble salts in the soil profile. The Na ion accumulation results in the occurrence of a natric or salic horizon (FAO, 2000; Soil Survey Staff, 2006). The profile characteristics of salt affected soils are also different due to different climates and soil environments. Under temperate climatic soil environment, top soils commonly show an accumulation of soluble salts as Az or Azg horizons. The subsoils usually show the accumulation of sodium, gypsum, soluble salts and carbonates without accumulation of silicate clays. However, some areas show accumulation of silicate clays with sodium and soluble salts. Moreover, their profiles usually have a saprolite layer (C horizon) at a shallow depth (Seelig *et al.*, 1990; Heck and Mermut, 1992). Whereas, under a tropical climatic soil environment, most salt affected soils have an accumulation of sodium salt throughout the soil profiles and also the argillic horizon. Some of these soils have a carbonate accumulation in their profiles and some also have a weathered rock layer being the source of salts at the bottom of profiles (Suddhiprakarn and Kheoruenromne, 1998; Kaewmano *et al.*, 2006; Wongpokhom *et al.*, 2008).

Salt affected soils normally have diverse colors depending on major soil forming factors and pedogenic processes (Brady and Weil, 2007). However, many salt affected soils have a gleyic color patterns at some depth. In lowlands, they have low chroma and with the presence of mottles. Their color ranges from dark grayish brown to gray, low chroma and presence of mottles clearly indicate the poor drainage and low leaching condition (Vepraskas and Wilding, 1983; Buol *et al.*, 2003). These conditions are favorable for salt accumulation (FAO, 2006; Fuchs *et al.*, 2006). Salt affected soils in the Central Plain of Thailand have diverse colors. In lowland areas they have low chroma and with the presence of mottles while in upland areas they have brown to dark brown colors (Suddhiprakarn and Kheoruenromne, 1998). Generally, the Btn horizon contains high amounts of clay and exchangeable sodium and is tough, dense and impermeable, affecting the penetration of both water and

plant roots (Levy, 2000; Soil Survey Staff, 2006). Clay is dispersed and moved into the subsoil, forming a dense accumulation horizon, the natric horizon (FAO, 2000). The soils have moderate to strong prismatic or columnar structure (Heck and Mermut, 1992). It was found that sodic soils have a brown color in upland position and have a gray color in wetland position. However, sodic soils have a high level of exchangeable Na^+ and pH value that exceeds 8.5, organic matter is dispersed through the soil matrix, rendering the soil black (Seelig *et al.*, 1990)

Micromorphology

Salinity and salt manifest their effects through micromorphological features of soils. The natric horizon shows a specific fabric. The peptized plasma in the natric horizon shows a strong orientation in a mosaic or parallel striated pattern. The plasma separations also include associated humus and microcrusts, cutans, papules and infilling appear when the natric horizon is impermeable (FAO, 2000). In addition, several researchers reported that pores in salt affected soils generally are vughs and channels. Salt crystals are commonly found in the soil profile and in vughs (Kooistra, 1983; Rojanapremasuk, 1990; Vichiansinpa, 1992; Kaewmano, 2003). Calcite, weathered feldspars, mica and gypsum are present in the fabric of salt affected soils derived from marine deposits and calcareous materials with cracks and fissure pore features indicating the influences of fine clay and a long period of water saturation within the soils (Suddhiprakarn and Kheoruenromne, 1998).

Halite (NaCl) and thenardite (NaSO_4) are the two most abundant salt minerals in the deposits of the Otjomongwa pan, southwestern Kalahari, Namibia. Thenardite occurs exclusively as coatings and infillings of voids. Halite only occurs as coatings consisting of anhedral crystals. It always covers thenardite where both minerals occur together (Mees, 2003).

The micromorphological features of salt affected soils in Northeast Plateau Thailand show that their microstructures are different due to differences in their texture. The distribution of coarse and fine materials is open porphyric, with quartz as

the main skeleton materials. Pores are mainly accommodated planar voids with few vughs. Crystalline pedofeatures include impure crystalline halite coatings on the walls of voids and mixed with fine material in the s-matrix and the the presences of barite (BaSO_4), sylvite (KCl) and calcite (Wongpokhom *et al.*, 2007; 2008). Clay accumulation features are clay quasi-coatings in peds and coatings around quartz grains.

In addition, some salt affected soils show accumulations of nodules and concretions of Fe-oxides and Mn-oxides, carbonate nodules and runi-quartz (Vichiansinpa, 1992; Wongpokhom, 2008). The accumulation of Fe-oxides and Mn-oxides indicate that the soil system has experienced oxidation-reduction processes (James and Bartlett, 2000; Buol *et al.*, 2003).

Physical Characteristics

The ionic composition and concentration of the soil solution in these soils affect soil physical properties. Most salt affected soils are adversely affected by the presence of excess Na in the soil solution and as an exchangeable cation (Keren, 2000). The accumulation of dispersive cations, such as Na (sometimes Mg and K), promotes clay swelling and/or dispersion altering the geometry of soil pores which, in turn, affects intrinsic soil permeability, water retention and crop productivity (Levy, 2000; Toth and Jozefaciuk, 2002). In general, salt affected soils may have poor physical properties. Saline soils often are in normal physical condition with good structure and permeability. The combination of high levels of sodium ions and low salinity in sodic soils tends to disperse soil particles, making the soil in physical properties poor (Lamond and Whitney, 1992).

Particle size distribution

Particle sizes and their relative abundance sharply influence most physical properties of salt affected soils (Skopp, 2000; Levy *et al.*, 2005). The particle size distribution of these soils varies within soil profiles. The texture of these soils

generally varies from loamy sand to clay, which relates to their parent materials. Normally, the amounts of clay particle size increase in some layers. Salt affected soils derived from glacial deposits have the textures of sandy clay loam to clay (Heck and Mermut, 1992). In calcareous saline-sodic soils, silt particles are dominant, amounting to 590-700 grams per kilogram; sand is usually less than 70 grams per kilogram and clay is 260-300 grams per kilogram (Lebron *et al.*, 1994). Salt affected soils derived from mixture of alluvium and eolian deposits have 500-800 grams per kilogram of silt and 150-400 grams per kilogram of clay (Toth and Jozefaciuk, 2002). Whereas, some saline-sodic soils developed on residuum derived from sedimentary rocks are sandy (Kaewmano, 2003).

Salt affected soils have major impacts on the flocculation or dispersion of clay minerals and organic matter (Chadwick and Graham, 2000). The clay fraction virtually always consists of a series of minerals quite different from the sand and silt fractions of a soil. Clay particles do not have a very strong preference for the cation species which help them to compensate for their built-in negative charge. Therefore, if initially the main adsorbed cation was Ca^{2+} , but the soil was affected continually by more Na^+ ions, the adsorbed Ca^{2+} would gradually be replaced by adsorbed Na^+ . When this happens the ESP, and hence the sodicity increase. Soils have a preference for cations with more than one positive charge, so it is easier to replace Na^{+1} on the exchange complex with Ca^{2+} or with aluminum (Al^{3+}) than to replace these in reverse order (van de Graaff and Patterson, 2001). Mono-valent ions like sodium are less effective in neutralizing the charge on the colloid and preventing swelling and dispersion than bi-valent or tri-valent ions like calcium and aluminium. Thus individual colloid particles continue to repel each other and stay in suspension (Brady and Weil, 2007).

Soil aggregate stability

Soil aggregates are held together by various organic and inorganic materials and by several mechanisms (Ben-Hur *et al.*, 1985; Chan and Mullins, 1994; Denef and Six, 2005). Consequently, many factors affect soil aggregate stability including

both internal and external factors. Internal factors include electrolyte concentration, exchange cation species, clay content, clay mineralogy and contents of carbonate, organic matter and iron- and aluminum-oxides. External factors include climate, biological activity and agricultural management (Goldberg *et al.*, 1988; Amezketa, 1999; Levy, 2000). Clay flocculation is a pre-requisite for the formation and preservation of soil aggregates (Dexter, 1988). Factors that strongly affect clay flocculation are clay mineralogy, electrolyte concentration (EC), pH, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) (Abu-Sharar *et al.*, 1978; Rengasamy and Olsson, 1991; Levy, 2000).

In mildly salt affected soils where halite is the major salt species, aggregates are generally unstable due to the presence of high amounts of dissolved sodium which causes sodicity (Tisdall and Oades, 1982) and associated swelling and dispersion of clay particles (Crescimano *et al.*, 1995). Exchangeable sodium weakens covalent associations between organic materials and soil minerals and increases the osmotic forces that cause particle repulsion during wetting. Even partial Na saturation greatly increases dispersion of macroaggregates and microaggregates (Rengasamy and Olsson, 1991; Levy, 2000).

Soil mineralogy has a substantial effect on aggregate stability and dispersion. Smectitic soils are the most dispersive followed by illitic and kaolinitic soils (Singer, 1994). Generally kaolinitic soils have the greatest aggregate stability (Wakindiki and Ben-Hur, 2002) and highly smectitic soils are more erodible than the soils that contain only minor amounts of smectite (Stern *et al.*, 1991). Aggregate stability is also influenced by clay content and aggregate stability is only closely related to sodicity for clayey soils (Frenkel *et al.*, 1978; Levy and Mamedov, 2002).

Bulk density

Bulk density of salt affected soil is generally high ($> 1.6 \text{ Mg m}^{-3}$) (Brady and Weil, 2007). Salt affected soils developed on wash and alluvium have high bulk density values of more than 1.6 Mg m^{-3} (Wongpokhom *et al.*, 2008). Similarly, the bulk

density of salt affected soils developed on colluvium and alluvium ranges from 1.5 to 2.2 Mg m⁻³ and values tend to be related to ESP values which are in the range from 8 to 105. Moreover, the bulk density value increases with increasing depth (Suddhiprakarn and Kheoruenromne, 1998).

Bulk density is highly dependent on soil conditions and it varies with the packing of soil of different particle sizes. Typically, sands pack more closely and values range between 1.4 to 1.9 Mg m⁻³. Clay tends to bridge and cannot be packed as tightly, giving values between 0.9 to 1.4 Mg m⁻³. Soils with textures between sand and clay differ in their bulk density. Changes in soil swelling due to changes in water content alter the bulk density (Skopp, 2000). The clayey-textured soils generally have lower bulk densities (El-Swaify, 1980). Baur and Black (1992) reported that soil bulk density decreased with the increase in organic carbon concentration and the magnitude of change was highest in sandy soils and lowest in medium textured soils.

Hydraulic conductivity

Soil hydraulic conductivity (HC) depends on the composition of the exchangeable cations and the composition and concentration of the electrolytes in the soil solution, as well as on soil texture and structure (Shainberg *et al.*, 2001). The hydraulic conductivity decreases with an increase in the ESP and the decrease in the total electrolyte concentration of the soil solution. The reduction in hydraulic conductivity has been attributed mainly to swelling and dispersion of the soil clay. The adverse effects of soil sodicity and salinity on soil hydraulic properties have been studied extensively (Levy, 2000).

The hydraulic conductivity of soils with high proportion of 2:1 clay minerals, high pH, and low sesquioxides content was found to be susceptible to sodic conditions, with the magnitude of the decrease in HC being strongly dependent on the electrolyte concentration in the soil solution (Shainberg and Letey, 1984). McNeal and Coleman (1966) found that increasing the sodium adsorption ratio and decreasing the electrolyte concentration of the percolating solution induced a decrease in soil

permeability. The hydraulic conductivity decreases with increasing sodium adsorption ratio (Karimpour, 2002; Rhoades *et al.*, 1992; Peng *et al.*, 2005). The reduction of hydraulic conductivity of saline and sodic soils was correlated with aggregate dispersion (Abu-Sharar *et al.*, 1987).

For a high ESP and low salt concentration, swelling of the clay is the main mechanism responsible for the decrease in hydraulic conductivity. At low ESP and very dilute soil solutions, dispersion and clay migration into the conducting pores are the main mechanisms responsible for plugging soil pores. Dispersion of clay particles is possible only when the concentration of the soil solution drops below a threshold concentration at which the clay platelets flocculate. In addition, dispersion is strongly dependent on soil texture and mineralogy (Pupisky and Shainberg, 1979). Felhendler *et al.* (1974) found that clay dispersion in soils with a low silt content was more pronounced than in soils with a similar ESP and clay mineralogy, but with higher silt content. The interacting effect of contrasting clay mineralogy, SAR, ESP and electrolyte concentration on the dispersion of soil colloids was studied by Velasco-Molina *et al.* (1971). They found that montmorillonitic and micaceous soils disperse more in weak salt solutions at low SAR values than do kaolinitic-halloysitic soils high in iron oxides. Hydraulic conductivity of sodic soils can decrease with leaching as a result of organic matter and clay dispersing together. Organic matter can prevent loss of permeability when SAR is low but not at high SAR. Dispersion ratios are strongly inversely correlated with organic matter contents in sodic soils with relatively low ESP values. However, additions of organic matter increase the dispersion of soil at high SAR, while its removal decreases the dispersion of sodium-saturated soils (Churchman *et al.*, 1993).

Chemical Characteristics

Electrical conductivity

The electrical conductivity of a saturation extract (EC_e) is a reliable indicator of solute concentration and it is a standard measure of the soil salinity (Friedman,

2005). In saline and saline-sodic soils, the EC of a saturation extract value is higher than 4 dS m^{-1} and varies with increasing depth. There are many factors that affect the EC_e . Changes in electrical conductivity value normally related to season, climate, source of salt, depth of water table and soil properties (Corwin and Lesch, 2005b). The EC is usually high in the surface horizon in the presence of salt crust (Fernandez-Buces and Grabach, 2006). Moreover, the EC_e of the soil surface with a salt crust in a tropical climate is higher than in a temperate climate. The surface horizons of some salt affected soils in Thailand and Canada have high EC_e in a range of $218\text{-}315 \text{ dS m}^{-1}$ and 74 dS m^{-1} respectively due to evaporation (Heck and Mermut, 1992; Kaewmano, 2003). The soil salinity is high in the dry season. In top soils, salinity in dry season varies from $4\text{-}12 \text{ dS m}^{-1}$ but in wet season it varies from $1.5\text{-}3 \text{ dS m}^{-1}$ (Mondal *et al.*, 2001).

In some cases, the EC_e value in the weathered parent material or saprolite layer (Cr) is higher than in the subsoil horizon (B) because weathering of the parent materials and the release of soluble salts (Essington, 2004). Textural effects also exist. The EC_e value of the coarse-textured soils is higher than that of the fine-textured soils because at saturation soils higher in sand have lower water contents than soils higher in clay (Corwin and Lesch, 2005a). In addition, soil texture affects the flow of water through soil. It also affects the depth of water table necessary to cause salinization. Coarse-textured soils allow upward capillary movement of water to occur only over a short distance. However, because the large pores in coarse-textured soils offer much less resistance to water flow compared to the smaller pores in fine-textured soils, salinization can occur much quicker in coarse-textured soils (Corwin and Lesch, 2005b).

Sodium adsorption ratio and exchangeable sodium percentage

The sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are the standard measures of the sodicity of a soil. The sodium adsorption ratio gives information on the comparative concentrations of sodium, calcium and magnesium ions in soil solution. The exchangeable sodium percentage identifies the degree to which the exchange complex is saturated with sodium (Brady and Weil, 2007).

The sodium adsorption ratio and exchangeable sodium percentage of most salt affected soils are higher than 13 and 15 respectively. General patterns of sodium adsorption ratio and exchangeable sodium percentage tend to be associated with electrical conductivity which is highest in the top soil (Heck and Mermut, 1992; Kaewmano *et al.*, 2006; Wongpokhom *et al.*, 2008). However, the exchangeable sodium percentage value is also related to the amount and type of clay minerals (Levy, 2000; Skopp, 2000).

Mineralogical Characteristics

Results of many studies on salt affected soils show that these soils generally have mixed mineralogy (Vichiansinpa, 1992; Suddhiprakarn and Kheoruenromne, 1998; Pal *et al.*, 2003; Kaewmano *et al.*, 2006). McNeal and Coleman (1966) reported that the highly salt-affected soils are dominated by smectite and kaolinite. Low (1980) reported that smectite is the dominant soil mineral in arid and semi-arid zones. Many studies on salt affected soils in Thailand showed that clay minerals of salt affected soils include smectite, kaolinite and illite. Generally, kaolinite is the dominant clay mineral with the trace of smectite (Hoontrakul, 1988; Vichiansinpa, 1992; Songsawadi, 1994; Suddhiprakarn and Kheoruenromne, 1998; Promdecha, 2001). However, in some areas, amounts of smectite increases in salt affected soils and may be higher than kaolinite (Kaewmano, 2003). This may be the result of the increasing solubility of silica in the saline water inducing resilication since alkaline conditions can increase the solubility of silica in soils (Jackson *et al.*, 1948; Alexander *et al.*, 1954; van Breemen and Buurman, 2002). As Wongpokhom *et al.*, (2008) reported the element composition of the salt affected soil matrix in a triangle graph of SiO_2 : Al_2O_3 : Fe_2O_3 is displaced from the 'kaolin line' towards the SiO_2 apex, indicating that very fine-grained quartz and/or a Si-rich clay mineral (s) is present in the matrix. The presence of Si-rich clay minerals is supported by XRD results that identified smectite in addition to kaolin and may be an evidence of the resilication process that can occur in salt affected soils.

The principal salts involved in salt affected soils are NaCl, CaCl₂, MgCl₂, NaHCO₃, Na₂CO₃, NaSO₄, MgSO₄, CaSO₄ and NaNO₃ (Zonn, 1986). In arid and semi-arid areas the salts generally are sulfate, carbonate and bicarbonate (Williams and Semple, 2001). Under arid environments of Virgin River floodplain of Southeastern Nevada, salt affected soils are dominated by halite, gypsum, bloedite, thenardite and eugsterite (Morton *et al.*, 2006). In the Baikal Region of Russia, the soils are mostly characterized by a predominance of halite (Chernousenko, 2006). In the salt crusts of solonchak soils in Western Siberia are predominated by thenardite and halite (Lebedeva, 2006). Most salt affected soils in Thailand have high amounts of sodium chloride (Hoontrakul, 1988; Vichiansinpa, 1992; Songsawadi, 1994; Suddhiprakarn and Kheoruenromne, 1998; Promdecha, 2001; Kaewmano, 2003; Wongpokhom *et al.*, 2008).

Salt Affected Soils in The Northeast Plateau Basins

In the Northeast Plateau, salt affected soils are found in Khorat and Sakon Nakhon Basins. The Department of Land Development (2003) compiled various soil maps of salt affected soils. The map units are defined by the presence of salt patches on the soil surface in dry season into highly salt affected area (0.24 million hectares), moderately salt affected area (0.59 million hectares), slightly salt affected area (2.02 million hectares), potential salt source area (3.14 million hectares) and salt free area (10.9 million hectares) (Yuvaniyama, 1994). In the Khorat Basin, salt affected areas can be found in every province of the basin. The highly and moderately salt affected areas are mostly distributed as small spots in the western fringe of the Khorat Basin. Whereas, the slightly salt affected areas are widely distributed as large spots in some parts of each province. In the Sakon Nakhon Basin, salt affected areas are mainly in the Udon Thani province, especially in the southwest part of the province, and most of them are only slightly salt affected.

The formation of salt affected soils in this plateau is closely related to geology and landform. Based on the geologic map of Northeast Plateau (Department of Mineral Resources, 1985), the Northeast Plateau Basins are underlain by rocks of the

Mahasarakham Formation of the Mesozoic Khorat Group (KTms). The salt-bearing beds belong mainly to the upper part of the Mahasarakham Formation, which are mostly sandstone, siltstone and shale (Piancharoen, 1973; Sinanuwong and Takaya, 1974; Takai *et al.*, 1987). In addition, salt domes of the Mahasarakham Formation occur in several places. Over 90 percent of salt affected area occurs on the area that is underlain by Mahasarakham Formation and Quaternary Deposits (Department of Mineral Resources, 1985).

There are three published hypotheses about the formation of salt affected soils in Northeast, Thailand. One hypothesis is that the salinization of the soils in the low-lying terrain is caused by seasonal downward or lateral seepage, or by capillary movement from shallow saline groundwater which may be derived from remnants of salt in near-surface beds of the salt formation somewhere upstream (Sinanuwong and Takaya, 1974). A second hypothesis is that salts have already accumulated in the groundwater as a result of geological erosion, and are later precipitated in the weathered zones following gradual dissection of the weathered mantle (Haworth *et al.*, 1966). A third hypothesis is that cyclic salt is brought in by rain or dry fallout (Takai *et al.*, 1987). Secondary salinization of the soils has also been observed. It has been reported that rice cultivation on the lower slopes, deforestation, extensive land clearing, saline seepage, rising saline groundwater and saline irrigation water may cause secondary salinization of the soils in the basins (Ghassemi, 1995; Sukchan and Yamamoto, 2003).

Northeast Plateau Basins are gently undulating plateau which are in the form of alluvial plain, terraces at various levels and erosional surface (Moorman *et al.*, 1964; Kheoruenromne, 1991). According to the map of salt affected soil distribution, soils in the salt affected areas include Roi Et (Re), Kula Ronghai (Ki) and Phimai (Pm) series which occur on low terraces and alluvial plain (Panichapong, 1981). Regarding soil salinization in the Northeast Plateau, Puengpan *et al.* (1991) reported that salinization occurs rapidly in two steps. Firstly, salts in the saline groundwater accumulate near the soil surface during dry season. Then, the accumulated salts are transported to foot slopes by runoff water. As a result, salt affected areas expand

quickly to low-lying paddy fields. Their distribution is related to the land forms of this region. The high terraces and central parts of middle terraces are not salinized. The foot slope of middle terrace, low terraces and alluvial plains are frequently salinized (Sinanuwong and Takaya, 1974). Vichiansinpa (1992) reported that salt affected soils in Khorat Basin occur on the low terrace region. Soils that have high salinity and high alkaline reaction are in depressions low terraces whereas soils that have salinity and acid reaction are on low alluvial terraces. Similarly, Ramsot (2005) reported that salt affected soils that have developed on a floodplain are acid salt affected soils. In addition, Kaewmano (2003) concluded that salt affected soils in Nakhon Ratchasima Province are related to low terraces. Soils that occupy the middle part of the low terraces are severely salt affected.

According to Wongsomsak (1986), salt affected soils in Northeast Thailand include three major types based on their topographic and geological settings as follows:

a) Hilly region: This consists of hills and small valleys. Weathering zones in hilly and valley portions show similar features excepts the former has higher permeability. Hence, rain water in the hill portion easily percolates and seeps down within the weathering zone. This produces a salty perched groundwater above the impermeable layer in the valley and with capillary rise, salt comes up to the ground surface resulting into extensive salt affected areas. Thus, the amount of salt in bed rock and the strength of capillary rise are the factors controlling the extent of salinity (Hatton, 1990; Kohyama and Subhasaram, 1993).

b) Valley region: This has a gently undulating landform with a height difference between the low mound portion and flat lowland. Salt crust on soil surface occur at the boundary between these two surfaces and as sandy salt patches in the lowland. Salinization of the lowland valley is caused by short distance interflow which is supported by the fact, that almost whole lowland valley of the Basin is erosional rather than depositional (Tuckson *et al.*, 1982; Hattori, 1990).

c) Basin region: This is widely covered by flat lowland with alluvial deposits. Below this layer, weathering beds of the Mahasarakham Formation occur. Salt bearing beds generally exist at considerable depth. Therefore, salt crust formation is rarely observed on the soil surface except at the border between valley and basin regions. The salt distribution pattern in the alluvial plain is controlled by groundwater movement.

Salt affected soils are more often found extensively near and around salt domes than in places where these domes do not exist. This indicates that saline soil formation has a close relationship with salt domes (Hattori, 1990). Results of several studies reveal that most of salt affected soils in Northeast Plateau, Thailand are Alfisols as Natraqualfs and Endoaqualfs (Vichiansinpa, 1992; Songsawadi, 1994; Promdecha, 2001; Kaewmano, 2003; Ramsoot, 2005; Wongpokhom *et al.*, 2008).

MATERIALS AND METHODS

Sampling Sites

The study areas are located in the Khorat Basin which is part of the Northeast Plateau (Figures 1 and 2). The basin is rimmed by an escarpment of mostly steeply dipping sedimentary rocks with *cuestas* rising from 200-1000 m above MSL on its western, northern and southern margins. The central part of the basin is a gently undulating plateau elevated at 200 to 100 m above MSL composed of a shallow alluvial plain mixed with terraces and erosional surfaces (Moorman *et al.*, 1964; Kheoruenromne, 1991). The salt affected soil distribution map and soil map at scales of 1: 100,000 and other maps (topographic map, geological map) were used as base maps to select the study area. Twenty one profiles were collected from highly to slightly salt affected areas. They are under a tropical savanna climate (Aw) with an annual average rainfall of 700-2000 mm and temperature of 26-30 °C (Meteorological Department of Thailand, 2006). Geologically, the bedrock underlying this basin is mainly of the Khorat Group of Cretaceous-Tertiary age (Figure 3) consisting of a thick sequence of red clays, siltstone, sandstone and conglomerates. The central part of the basin is underlain mainly by Mahasarakham Formation and Quaternary Formation. The Mahasarakham Formation consists of siltstone, claystone and sandstone with frequent rock salt, potash, gypsum and anhydrite. The salt-bearing beds belong mainly to the upper part of this formation. The Quaternary Formation consists of terrace and fluvial deposits (Geological Survey Division Staff, 1985; Deeradilok *et al.*, 1992).

The environmental setting of these salt affected soils is shown in Table 1. They have been formed on mixed parent materials. A group was formed on shallow alluvium and/or wash deposit over residuum derived from clastic sedimentary rocks (Pedons 2, 4, 5, 8-9, 11-15, 17, 20 and 21) and another group on deeper alluvium and/or wash deposits (Pedons 1, 3, 6-7, 16, 18 and 19). Only one soil (Pedon 10) formed directly on residuum derived from sedimentary rock. The surrounding landforms are flat to gently undulating. These soils have developed at various

positions on low terraces and some soils on erosional plain and flood plains. Land use at the time of sampling was paddy field/ rice, left idle due to salt, local grasses, halophytic plants, tolerant grasses and a plantation of *Eucalyptus* sp.

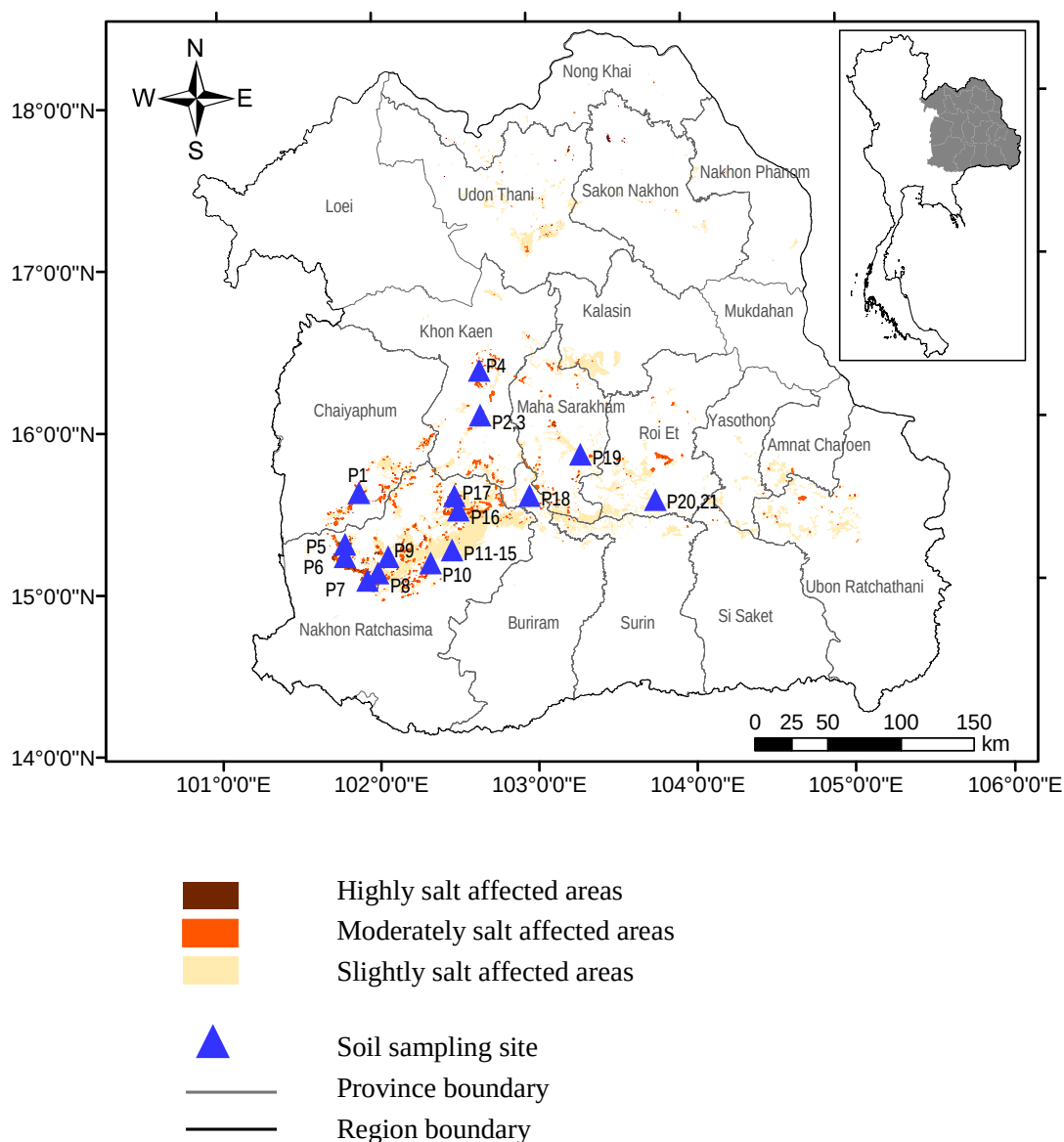


Figure 1 Location of sampling sites for salt affected soils in the Northeast Plateau of Thailand.

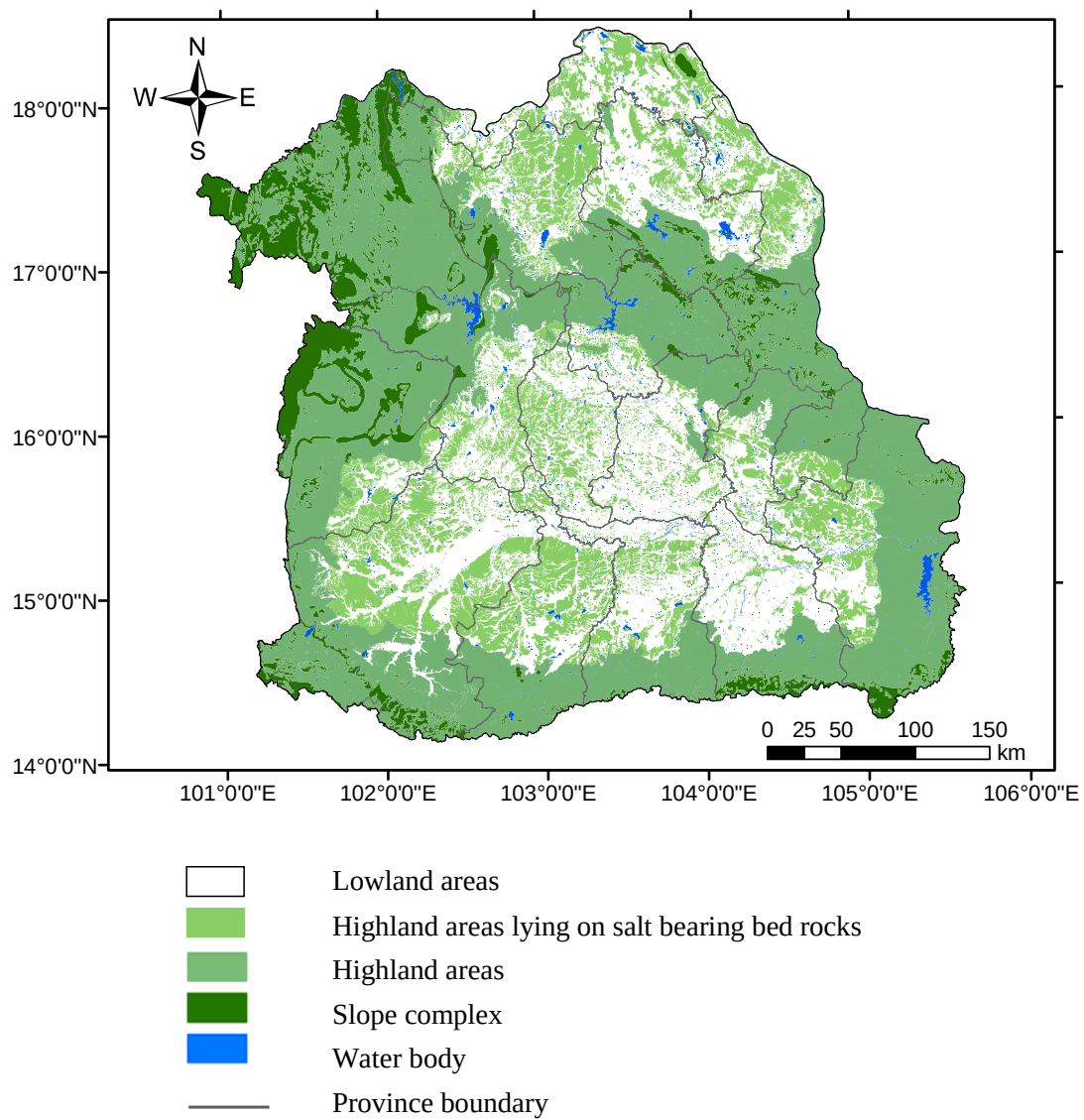


Figure 2 General physiography of Northeast Plateau, Thailand.

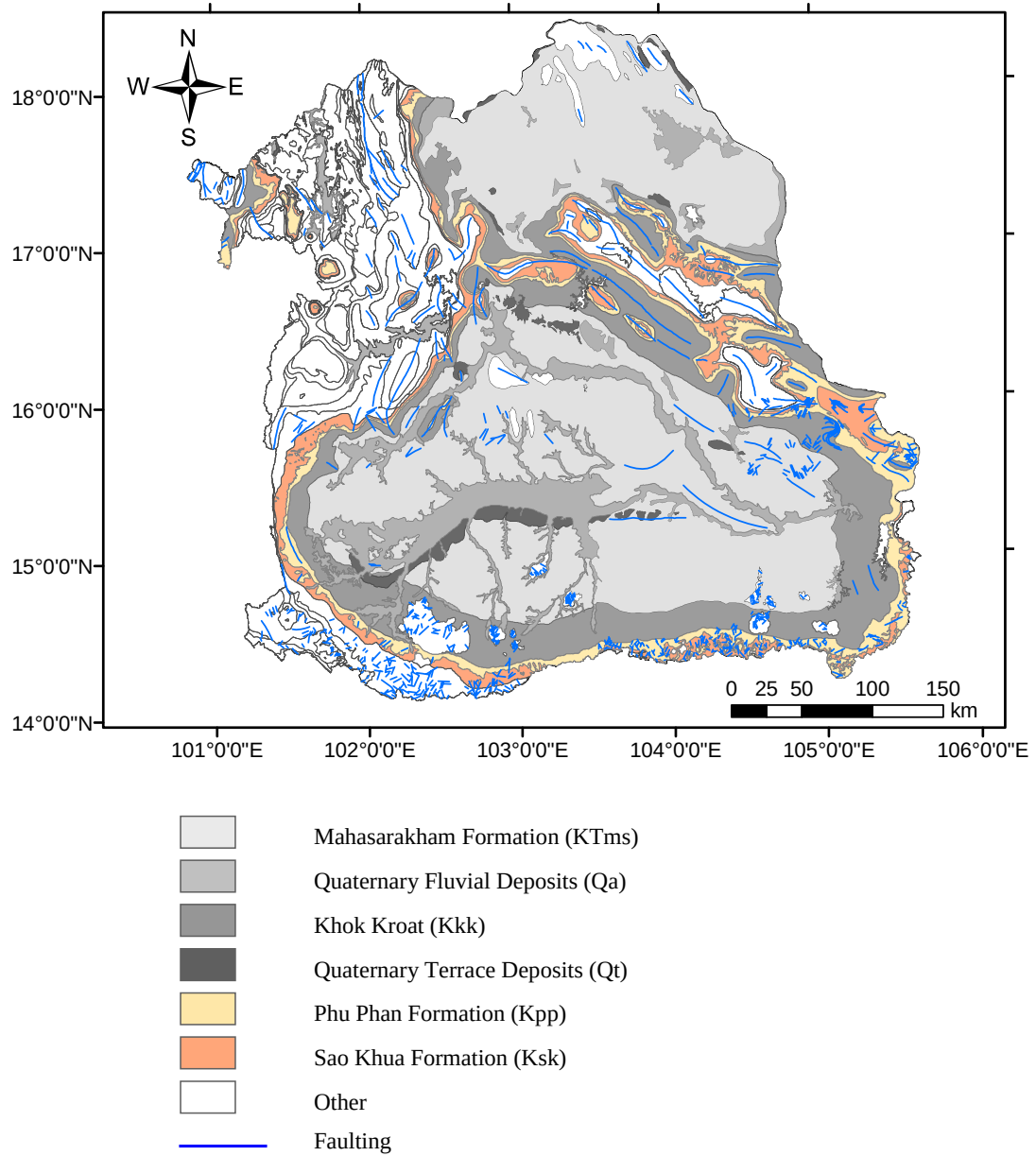


Figure 3 Geology of the Northeast Plateau, Thailand.

Table 1 Environmental setting of the salt affected soils.

Location	Profile	Physiographic position	Probable parent material	Surrounding landform	Slope (%)	Elevation (m MSL)	Rainfall (mm y ⁻¹)	Land use
<i>Chaiyaphum</i>	Pedon 1	Depression strip in low terrace	Local alluvium and wash deposits	Gently undulating	2	185	923	Left idle under grasses and shrubs
<i>Khon Kaen</i>	Pedon 2	Depression on erosional plain	Alluvium over residuum derived from clastic sedimentary rock	Flat	2	152	194	Left idle under local grasses
	Pedon 3	Depression on erosional plain	Alluvium	Flat	2	152	949	Left idle under salt tolerant grasses
	Pedon 4	Low terrace	Wash over residuum derived from clastic sedimentary rock	Flat	1	178	1025	Paddy/left idle because of salt effect
<i>Nakhon Ratchasima</i>	Pedon 5	Low terrace	Local alluvium and wash deposit over residuum derived from sedimentary rock	Flat	1	203	907	Paddy/left idle under local grasses
	Pedon 6	Lower part of low terrace	Riverrine alluvium	Gently undulating	3	185	907	Paddy/local grasses
	Pedon 7	Depression on low terrace	Local alluvium and wash deposits	Gently undulating	2	192	933	Left idle
	Pedon 8	Depression on low terrace	Alluvium over residuum	Gently undulating	2	165	974	Disturbed paddy field
	Pedon 9	Low erosional terrace	Local alluvium derived from basic rocks overlaying residuum	Flat	1	184	833	Paddy/ left idle under local grasses
	Pedon 10	Low erosional terrace	Residuum derived from sedimentary rock	Gently undulating	2	162	955	Paddy/ left idle under local grasses

Table 1 (Continued)

Location	Profile	Physiographic position	Probable parent material	Surrounding landform	Slope (%)	Elevation (m MSL)	Rainfall (mm y ⁻¹)	Land use
	Pedons 11-12	Flood plain	Alluvium over residuum derived from fine grained sedimentary rock	Flat	1	151-153	975	Paddy field, left idle
	Pedon 13-15	Floodplain or strath terrace on floodplain	Alluvium over residuum derived from clastic sedimentary rock	Gently undulating	2	151-153	975	Paddy rice ploughed at time of sampling, <i>Eucalyptus sp.</i>
	Pedon 16	Middle part of low terrace	Local alluvium derived from calcareous rock	Gently undulating	2	160	1032	Paddy rice
	Pedon 17	Erosional plain	Wash over residuum derived from weathered clastic sedimentary rock	Gently undulating	2	160	1006	Paddy field, left idle under local weeds, salt tolerant species
<i>Buriram</i>	Pedon 18	Depression on low alluvial terrace	Mixed local and riverine alluvium	Gently undulating	2	144	111	Transplanted rice
<i>Maha Sarakham</i>	Pedon 19	Low alluvial Terrace	Local alluvium/wash deposit mainly	Gently undulating	3	146	1040	Paddy rice
<i>Roi Et</i>	Pedons 20-21	Erosional plain	Wash over residuum derived from clastic sedimentary rock	Flat	2	116-117	1237	Paddy rice/ Eucalyptus

Field Analysis and Sample Preparation

Pedon analysis in soil pits was carried out at each site including detailed profile description and sampling of soil from each genetic horizon according to standard field study methods (Soil Survey Division Staff, 1993; Kheoruenromne, 1999). Disturbed bulk samples, clod samples, core samples and Kubiena samples were collected for laboratory analysis.

Bulk samples were air-dried, crushed and then passed through a 2-mm sieve for general laboratory analysis. The clod samples were used for bulk density measurement. The core samples from topsoil were used for hydraulic conductivity measurement. Soil aggregates (1 to 2-mm) which are the most abundant aggregate size class were separated by sieving for analysis of aggregate stability. Kubiena samples were transferred to impregnation mould containers, oven dried at 50-60 °C for several days up to a week with no shrinkage and impregnated with resin before slicing to prepare uncovered thin sections on glass slides (Cady *et al.*, 1986) for optical microscopy. Oil was used as a lubricant to prevent the dissolution of soluble salts during thin section preparation.

Laboratory Analyses

A summary of methods for physical, chemical, mineralogical and micro-morphological analyses used in the study is shown in Table 2. The details of each method are in the Appendix B.

Table 2 Laboratory methods.

Analysis	Method	Reference
Physical analysis		
Particle size analysis	Pipette method	Gee and Bauder, 1986
Hydraulic conductivity	Falling-head method	Klute and Dirken, 1986
Bulk density	Clod method	Blake and Hartge, 1986
Aggregate stability	Wet aggregates	Kemper and Rosenau, 1986

Table 2 (Continued)

Analysis	Method	Reference
<i>Chemical analysis</i>		
Soil pH	1:1 soil:solution in H ₂ O, 1N KCl by pH meter	National Soil Survey Center, 1996
Organic carbon	Wet digestion and titration by Walkley-Black method	Nelson and Sommers, 1996
Organic matter	Organic carbon concentration x 1.724	
Available P	Bray II	Bray and Kurtz, 1945
Extractable bases (Ca ²⁺ , Mg ²⁺ , Na ⁺ and K ⁺)	1 N NH ₄ OAc at pH 7.0 extraction and measured by AAS	Thomas, 1987a
Extractable acidity	Barium chloride-triethanolamine solution at pH 8.2	Thomas, 1987b
Cation exchange capacity - CEC by NH ₄ OAc	Saturating the exchange site and displacing by 1N NH ₄ OAc at pH 7.0	Chapman, 1965
- CEC by summation of cations	Sum of extractable bases plus extractable acidity	National Soil Survey Center, 1996
Base saturation percentage	By sum of bases extracted by NH ₄ OAc pH 7.0, divided by the CEC by sum of cations and multiplied by 100	National Soil Survey Centre, 1996
Electrical conductivity	Saturation extract methods at 25°C and measured by electrical-conductivity bridge	U.S. Salinity Laboratory Staff, 1954
Sodium adsorption ratio (SAR)	Calculation of SAR by dividing the molar concentration of the monovalent cation Na ⁺ by the square root of the molar concentration of the divalent cations Ca ²⁺ and Mg ²⁺ (meq L ⁻¹)	U.S. Salinity Laboratory Staff, 1954
Exchangeable sodium percentage (ESP)	Calculation of ESP by dividing the exchangeable sodium (ES) by the CEC-7 and multiplying by 100	U.S. Salinity Laboratory Staff, 1954
<i>Micromorphological analysis</i>		
Micromorphological features	Polarizing microscope technique	Bullock <i>et al.</i> , 1985
Chemical composition of the micromorphological features	Scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS) on JEOL 6400 SEM	White and Dixon, 1995
<i>Mineralogical analysis</i>		
Mineralogical characterization	X ray diffraction (XRD) analysis (silt and clay fraction)	Brindley and Brown, 1980
<i>GIS analysis</i>		
Isohyetal line	Inverse Distance Weighted Interpolation Method	Aguilar <i>et al.</i> , 2005; Chaplot <i>et al.</i> , 2006; ESRI, 1993
The relationship between salt affected soils and spatial factors	Overlaying	

RESULTS AND DISCUSSION

Soil Characteristics

Field Morphological Properties

The surface of these salt affected soils commonly has a continuous or patchy salt crust. The morphology of these soils indicates the impact of former erosional processes and depositional processes (Butzer, 1976; Buol *et al.*, 2003) (Figures 4-7, Table 3). As a result, many soil profiles (Pedons 2, 4-5, 8-9, 11-15, 17, 20 and 21) show lithologic discontinuities. The upper part of their profiles shows various thicknesses of transported materials and the lower part of their profile is residuum mainly derived from sedimentary rocks. In the residual layer of Pedon 9, calcareous siltstone fragments are present and lime nodules have accumulated. The soil profiles (Pedons 1, 3, 6-7, 10, 16 and 19) that do not contain the residual layer within 2 meters indicate the greater influence of depositional processes (Bujan *et al.*, 2003).

All soils are deep (except Pedon 9) and exhibit clay accumulation in their subsoils (Bt), possibly attributed in part to illuviation and lessivage (Buol *et al.*, 2003) indicating a high stage of profile development (Soil Survey Staff, 2006). The soil horizons show clay coatings on ped faces and pores walls and clay bridges among sand grains. Accumulations of soluble salts occur in both topsoils (An) and subsoils (Bn). However, some soils have no salt accumulation in the upper part of their profiles (Pedons 13, 15, 20 and 21) and throughout the profile of Pedons 14 and 16. Lime nodule accumulation (Bk, Ck) in the lower part of Pedon 9 and 16 is associated with their calcareous parent material. Soil matrix color differs between profiles. Clayey soils have a darker color. Most soils have low chroma (≤ 2) and are mottled indicating that they have poor drainage and a long period of water saturation (Bg) (Megonigal *et al.*, 1993; He *et al.*, 2003). Thus, these soils have a slow leaching condition where salt can translocate down from soil surface to accumulate in subsurface horizon (Soil Survey Division Staff, 1993; Boul *et al.*, 2003). Common soil structures are moderate to strong subangular blocky and angular blocky. Some

horizons have semimassive to massive (Pedons 2, 3, 10-11, 13, 15, 17, 20 and 21) and prismatic (Pedons 16 and 18) structures. Most soils have firm to very firm consistence when moist and are moderately sticky and moderately plastic when wet. However, some horizons especially the surface soils have friable consistence when moist and are slightly sticky and slightly plastic when wet. This is due to the high sand and low clay contents in these horizons. Soil containing much clay displays the properties of plasticity and cohesiveness reflecting the amount and mineralogy of the clay (Yalcin, 2007). The field pH range for these soils is 4.5-8.5 and field pH of most soils is higher than 7.0 particularly the subsoil horizons.

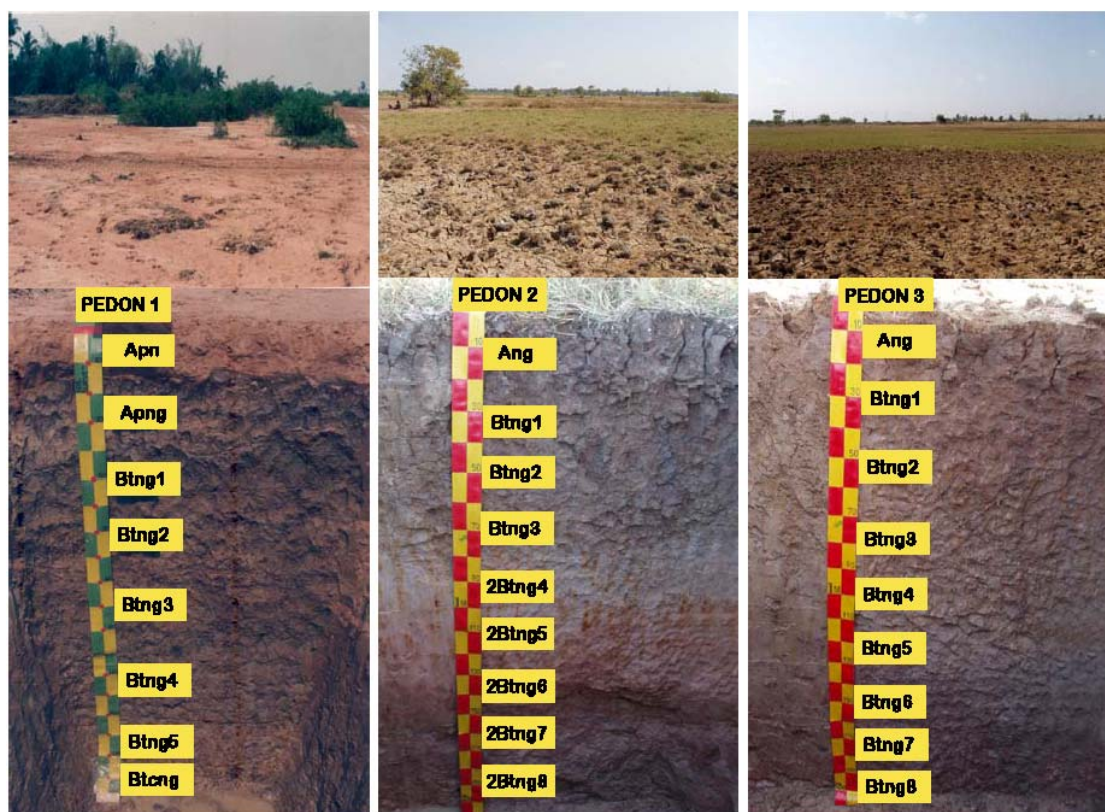
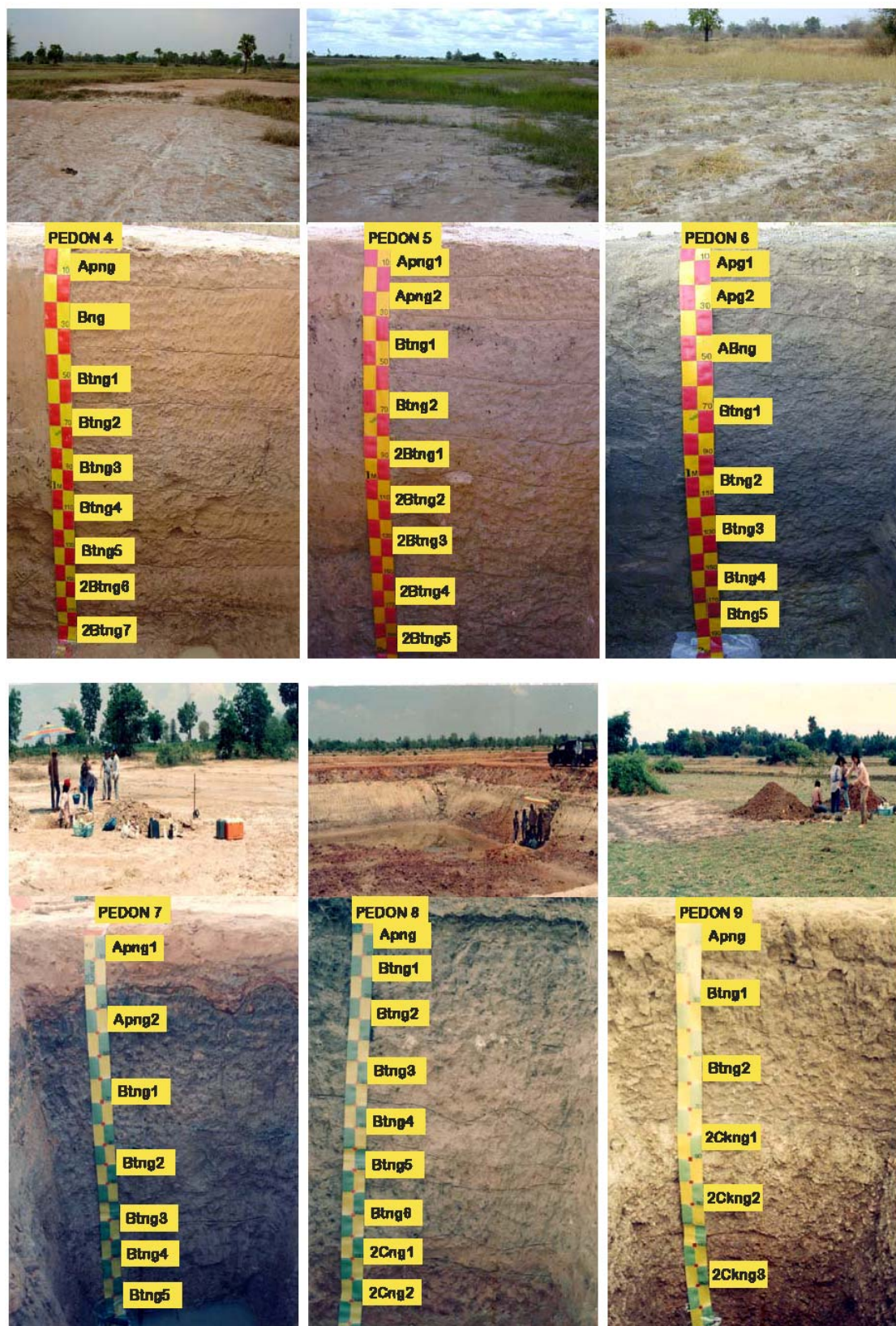


Figure 4 Soil profiles of salt affected soils for Typic Natraqualf (Pedon 1) and Vertic Natraqualfs (Pedons 2 and 3).



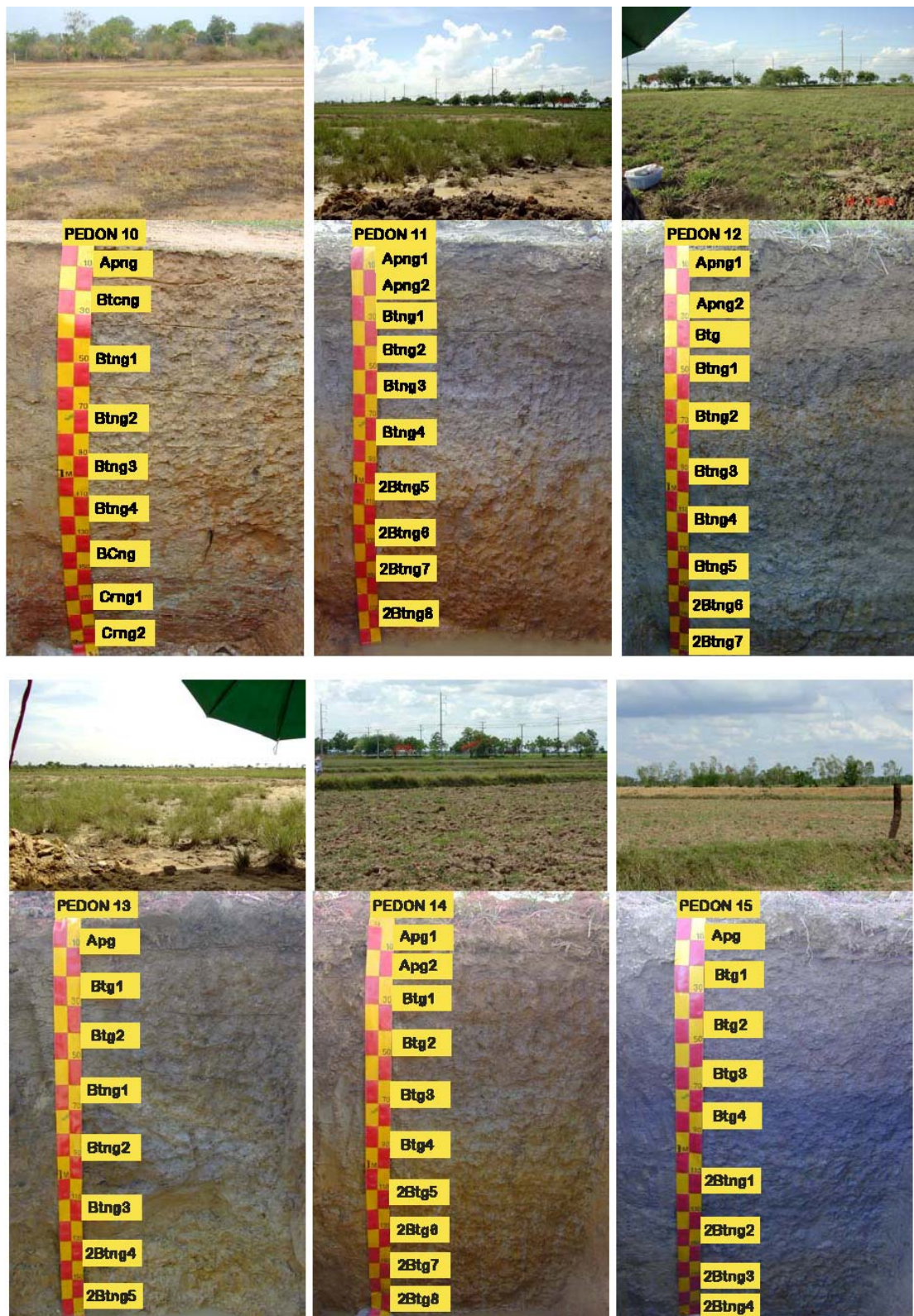


Figure 6 Soil profiles of salt affected soils for Typic Natraqualfs (Pedons 10-13 and 15) and Typic Endoaqualf (Pedon 14).

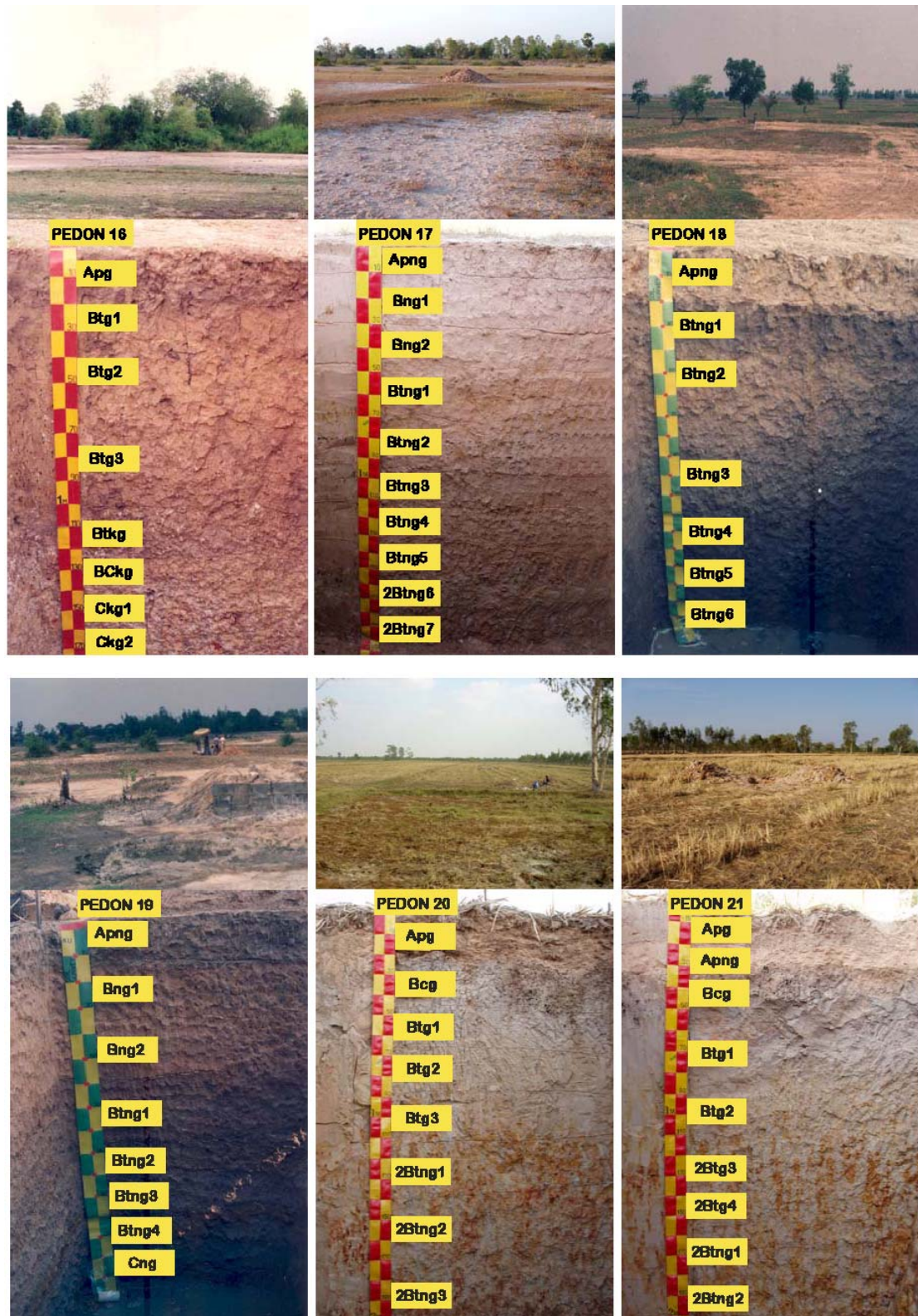


Figure 7 Soil profiles of salt affected soils for Aeris Kandiaqualf (Pedon 16) and Typic Natraqualfs (Pedons 17-21).

Table 3 Morphology of salt affected soils in Northeast Plateau, Thailand.

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedon1</i>	<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>					
Apng	0-30/40	2.5YR 5/6, 7.5YR 4/2	7.5YR 6/8	1 SBK	VF, NS/NP	Salt crust
Btng	40-172	7.5YR5/2, 5/4, 5YR 7/3, 7/2	2.5YR 4/8, 7.5YR 5/8	2-3 SBK	SF, SS/SP	-
Btcng	172-180	5YR 7/2	7.5YR 5/8	2SBK	SF, SS/SP	-
<i>Pedon2</i>	<i>Vertic Natraqualf, fine-loamy, mixed, isohyperthermic</i>					
Ang	0-19	10YR3/3,4/3	10YR 4/6, 5/8	1 ABK to se-M	VF, VS/VP	Salt patch
Btng	19-77	10YR 4/3,6/2	10YR 4/6, 7.5YR 4/6, 2.5YR 4/8	1 ABK to se-M	VF, VS/VP	-
2Btng	77-210	10YR 6/3, 7.5YR6/4,6/6, 5YR 6/6	10YR 3/4, 4/4, 5/8, 2.5YR 4/8, 5/6, 2.5Y 2.5/1	1 ABK to se-M	SF-SFri, SS/SP	-
<i>Pedon3</i>	<i>Vertic Natraqualf, fine-loamy, mixed, semiactive, isohyperthermic</i>					
Apng	0-21	10YR 4/2	7.5YR 5/6	1 ABK, se-M	VF, VS/VP	Salt patch
Btng	21-200	10YR 4/2, 7/2,5/2, 2.5Y 6/1	10YR 5/8, 4/8, 7.5YR 5/8, 2.5YR 4/8	2 ABK, se-M	VF, VS/VP	-
<i>Pedon4</i>	<i>Typic Natraqualf; coarse-loamy, mixed, ishyperthermic</i>					
Apng	0-12	10YR 6/2, 5/2, 7.5YR 7/6	-	2 se-ABK	SFri, SS/SP	Salt crust
Bng	12-37	7.5YR 7/6	10YR 6/8, 7.5YR 6/8	1 se-ABK	F, NS/NP	-
Btng	37-140	7.5YR 7/6, 6/4, 10YR 6/6	10YR 5/8, 6/8	2 SBK, 2 se-ABK, 2-3 ABK	SFri-F, SS/SP-MS/MP	-
2Btng	140-190	7.5YR 7/6, 6/4, 10YR 6/6	10YR 5/8, 6/8	2 se-ABK, 2 ABK	F, MS/MP	-
<i>Pedon5</i>	<i>Typic Natraqualf, fine-loamy, mixed, isohyperthermic</i>					
Apng	0-28	10YR 4/3, 7.5YR 5/4, 6/4	5YR 5/6, 4/6, 10YR 2/1	2-1 SBK, 2 se-ABK	VFri-Fri, NS-SS/MP-VP	Salt crust
Btng	28-80	7.5YR 5/4, 10YR 5/2, 6/2	7.5YR 2/0, 5/8	2 se-ABK, 3 ABK	F-VF, SS-MS/MP-VP	-
2Btng	80-200	10YR 6/2, 6/3, 7/2	7.5YR 5/8,4/6, 5/5, 5/0	3 ABK	VF, MS/VP	

Table 3 (Continued)

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedon6</i>	<i>Typic Natraqualf; fine, mixed, isohyperthermic</i>					
Apng	0-32/36	10YR 4/2, 4/1	7.5YR 5/0, 4/6	3 SBK, 3 ABK	VF, MS/MP	Salt patch
ABng	36-57	10YR 4/1	7.5YR 4/6	3 ABK	VF, MS/VP	-
Btng	57-195	10YR 4/1, 5/1, 5/2, 7.5YR 5/2	7.5YR 4/6, 5/8	2 ABK, 1-2 se-ABK	F-VF, SS-MP/MP-MP-VP	-
<i>Pedon7</i>	<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>					
Apng	0-52/55	10YR 3/2, 5YR 4/6, 5/3	7.5YR 2/0, 2.5YR 4/8, 10YR 3/6	2 SBK	VFri, SS/SP	Salt crust
Btng	55-190	5YR 6/3, 7/4, 7.5YR 7/4	7.5YR 2/0, 5/8, 10YR 3/0, 5YR 2/1	2 SBK, 1 ABK	SF, SS/SP	-
<i>Pedon8</i>	<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>					
Apng	0-20	5YR 4/2, 7/3	7.5YR 3/2	2 SBK	Fri, SS/SP	-
Btng	20-160/170	5YR 5/1, 6/3, 7/3	7.5YR 2/0, 7/6, 5YR 2/0, 3/2, 10YR 2/1	2 ABK, 2 SBK	Fri, SS/SP	-
2Cng	170-200	5YR 5/8, 7.5YR 6/2, 2.5YR 4/4	2.5YR 4/8, 2/4, 2/1	1 SBK	VFri, SS/SP	-
<i>Pedon9</i>	<i>Typic Natraqualf; fine, mixed, isohyperthermic</i>					
Apng	0-13/15	5YR 3/2	-	3 ABK	F S/P	
Btng	15-72	7.5YR 4/2, 5YR 4/4	5YR 6/8	3ABK	F, S/P	
2Ckng	72-190	5YR 4/4, 5/4, 2.5YR 5/8	5YR 6/8, 7.5YR 6/8	1 SBK	SF, SS/SP	Lime nodule, calcareous siltstone fragments

Table 3 (Continued)

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedon10</i>	<i>Typic Natraqualf; loamy-skeletal, mixed, isohyperthermic</i>					
Apng	0-15	10YR 4/2, 7.5YR 2/0	5YR 4/6, 2.5YR 4/6	2-1 ABK	Fri, SS/SP	Salt crust
Btcng	15-36	10YR 5/2, 2.5YR 3/4	7.5YR 4/6, 5YR 4/6	3 ABK	VF, MS/MP	-
Btng	36-125/130	10YR 5/2, 7/1 5/8, 4/6	10YR 5/8, 5/2, 2.5YR 4/6, 7.5YR 4/6	3 SBK, 3 ABK, 3 se-ABK	VF, MS/MP-VP	-
BCng	130-156	10YR 7/1	2.5YR 4/6, 10YR 5/8	3 ABK	VF, MS/MP	-
Crng	156-203	1YR 7/1	10YR 4/6, 5/8	M	VF, MS/MP	Rock structure
<i>Pedon11</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apng	0-20	7.5YR 3/3, 10YR 4/3, 4/6	10YR 4/4, 2.5YR 4/8	3 SBK, 3 se-ABK	F, MS/MP	Salt patch
Btng	20-114	10YR 5/2, 4/1, 2.5Y 4/2	10YR 5/8, 7/8, 5YR 5/8, 2.5YR 4/4	2 se-ABK, 2 ABK, 1 ABK to se-M	VF, MS/MP	-
2Btng	114-190	10YR 7/1, 7/2, 6/1, 6/3	10YR 4/1, 5/6, 7.5YR 4/6	1-2 ABK to se-M	F, SS/MP	-
<i>Pedon12</i>	<i>Typic Natraqualf; very fine, kaolinitic, isohyperthermic</i>					
Apg	0-30	7.5YR 3/2, 10YR 4/1	5YR 4/6	3 ABK, 3 se-ABK	VF, VS/VP	-
Btg	30-42	10YR 5/3	5YR 4/6	2 se-ABK	F, MS/MP	-
Btng	79-151	10YR 4/1, 5/1, 6/1, 6/2	7.5YR 5/4, 5/6, 10YR 5/4, 5/6, 5/8, 5YR 4/6	2 se-ABK, 2 ABK, se-M, 2 SBK, 1 ABK	F, MS/MP-VP	-
2Btng	151-200+	10YR 6/1, 7/2	10YR 5/8, 2.5YR 4/1	1 ABK, se-M	F, MS/MP	-

Table 3 (Continued)

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedon13</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apg	0-11	7.5YR 4/2	7.5YR 4/6	1 ABK, se-M	VF, MS/MP	-
Btg	11-56	10YR 5/3, 2.5Y 4/2	10YR5/6, 7.5YR 5/8, 2.5Y 5/6	2 se-ABK parting to 2 mG	F, MS-VS/MP-VP	-
Btng	56-124	2.5Y 5/3, 6/3, 10YR 6/1, 2.5Y 5/1, 6/2	2.5Y 6/4, 6/6	2 se-ABK parting to 2 mG, 2 ABK	F, MS-VS/MP	-
2Btng	124-180+	2.5Y 7/1	2.5Y 6/6, 5Y 4/6	1 ABK, se-M	F, MS/MP	-
<i>Pedon14</i>	<i>Typic Endoaqualf; fine, kaolinitic, isohyperthermic</i>					
Apg	0-22	10YR 4/2, 4/3	2.5YR 4/8, 5YR 4/6, 7.5YR 5/8	2 SBK, 3 ABK	F, MS/MP	-
Btg	22-102	7.5YR 4/3, 4/2, 10YR 4/2, 6/2, 5/3, 5/1, 2.5Y 6/3	10YR 4/6, 5/8, 7/8, 2.5Y 7/6,6/8	2 ABK	F-VF, MS/MP	-
2Btg	102-190+	2.5Y 6/2, 7/1, 7/4, 10YR 6/1, 7/2, 7/2, 2.5Y 7/4	2.5Y 6/8, 7.5YR 4/6, 10YR 4/1, 4/6 5/6, 6/8	2 ABK	F, MS/MP	-
<i>Pedon15</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apg	0-16	10YR 5/3	5YR 5/6	2 SBK	F, MS/MP	-
Btg	16-95	10YR 4/2, 5/2	7.5YR 5/8, 6/2, 6/8, 5YR 4/6, 2.5YR 5/8	2 se-ABK, 2-3 ABK	F-VP, MS-VS/MP-VP	-
2Btng	128-210+	2.5Y 5/2, 6/2, 6/4	2.5Y 6/6	2 fm, 1 se-ABK, 1 ABK, se-M	F, SS/MP	-
<i>Pedon16</i>	<i>Aeric Kandiaqualf; fine-loamy, mixed, isohyperthermic</i>					
Apng	0-18	10YR 3/2	10YR 5/6	3 ABK	Fri, SS/SP	-
Btg	18-101	7.5YR 4/2, 5/2, 6/2	10YR 5/6, 7.5YR 2/0	3 P To ABK	Fri, SS/SP	-
Btkg	101-123	10YR 6/4	10YR 5/6, 5YR 5/6	2 SBK	SF, SS/P	Lime nodules
BCkg	123-135	10YR 6/4	10YR 7/8, 2.5YR 5/6	2 SBK	SF, SS/P	Lime nodules
Ckg	135-195	10YR 6/4, 2.5Y 7/2	10YR 7/8, 2.5YR 5/8	2 SBK	SF, SS/P	Marl layer with lime nodules

Table 3 (Continued)

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedom17</i>	<i>Typic Natraqualf; sandy, silicious, isohyperthermic</i>					
Apng	0-11	7.5YR 7/3, 5YR 5/8	7.5YR 5/8, 4/2	1 SBK	Fri, SS/NP	Salt crust
Bng	11-47	7.5YR 7/2, 5YR 6/6, 6/8	7.5YR 5/8, 2.5/1, 10YR 7/8	1 SBK, 1 se-ABK	Fri, NS/NP	-
Btng	47-153	7.5YR 7/2, 5YR 5/8, 10YR 7/2, 2.5YR 6/6	10YR 6/8, 7/8, 5YR 5/8, 7.5YR 5/8	1 se-ABK, 2 se-ABK	SF-F, SS/SP	-
2Btng	153-200	7.5YR 7/3, 7/6, 10YR 7/1, 2.5YR 4/4	10YR 6/8, 8/8, 7.5YR 5/6	1 ABK, se-M	F-VF, MS/MP	-
<i>Pedon18</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apng	0-20/23	7.5YR 5/2	2.5YR 5/8	2 SBK	F, SS/SP	-
Btng	23-193	5YR 4/2, 5/3, 10YR 4/2, 3/2, 7.5YR 4/2	2.5YR 4/8, 7.5YR 7/8, 5YR 7/8, 10YR 5/8	2-3 SBK, se-P, 3 ABK	F-VF, S/P	-
<i>Pedon19</i>	<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>					
Apng	0-13/16	5YR 6/4	5YR 5/8, 2/1	2 SBK	Fri, NS/NP	Salt crust
Bng	16-58	5YR6/4, 6/6	7.5YR 5/8, 5YR 5/8	1 SBK	Fri-VFri, NS/NP	-
Btng	58-125/131	5YR 6/4, 6/3, 7.5YR, 5/8	5YR 6/8, 2.5YR 4/8	2 SBK	Fri, SS/SP	-
Cng	131-160	7.5YR 6/2	-	1 SK	SF, SS/SP	-
<i>Pedon20</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apg	0-15/23	10YR 6/2	10YR 5/6	1 SBK	Fri, SS/SP	-
Bcg	23-46	10YR 7/1	10YR 2/1, 10YR 6/8	M	VF, VS/VP	-
Btg	46-113	10YR 7/1, 2.5Y 7/1	10YR 6/8, 3/6, 2.5Y 7/8	1-2 ABK, 2 se-ABK	VF, VS/VP	-
2Btng	113-205	10YR 7/2	10YR 6/8, 10YR 3/6	2 se-ABK	F, MS/MP	-

Table 3 (Continued)

Genetic horizon	Depth (cm)	Matrix color	Mottle color	^A Structure	^B Consistence	Others
<i>Pedon21</i>	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>					
Apg	0-20	10YR 5/1, 7.5YR 5/3	10YR 6/8	1 se-ABK	Fri, SS/SP	-
Apng	20-27/32	7.5YR 7/4, 5/1	7.5YR 6/8	1 se-ABK	VFri, NS/NP	-
Bcg	32-54/63	10YR 7/1-2, 7.5YR 6/2	10YR 5/1, 2/1	M	VF, VS/VP	-
Btg	63-111/114	10YR 7/2, 7.5YR 7/1-2	2.5YR 6/6, 10YR 6/8	1 ABK, se-M	VF, VS/VP	-
2Btg	114-155	10YR 7/2, 7/1	10YR 5/8, 10YR 5/8	2 se-ABK	F-VF, VS-MP/VP	-
2Btng	155-207+	10YR 7/2	10YR 5/8, 6/8, 10R 5/8	2 se-ABK	F, MS/VP	-

^A Structure 1 = weak, 2 = moderate, 3 = strong, ABK = angular blocky, SBK = subangular blocky, M = massive, se-ABK = semi-angular blocky, se-M = semi-massive, P = prismatic

^B Consistence moist Fri= friable, SF= slightly firm, F= firm, VF= very firm, wet SS= slightly sticky, MS= moderately sticky, MP= moderately plastic, VP= very plastic

Physical Properties

The complete physical analyses of the soils are shown in Appendix Table 1. Soil texture varies from sand to clay, as affected by the parent materials (Figure. 8) (Osher and Buol, 1998). Texture ranged from sand to sandy clay loam in the soils that derived from local alluvium, wash deposits and residuum (Figure 9). The soils developed on (riverine) alluvium have finer texture as clay loam to clay for Pedons 3, 6, 12-15 and 18 and in the upper part of some soil profiles. However, soil texture of riverine alluvium (Pedons 6 and 18) varies in the profiles due to different episodes of sediment deposition (Gerrard, 1992). Systematically increasing clay percentage with depth occurs in many soils (Pedons 3, 5, 7-8, 10 and 16-19) and increases in clay percentage at some depths in subsoils are due to clay illuviation and lessivage where clay coatings can clearly be observed (Khademi and Mermut, 2003; Gunal and Ransom, 2006).

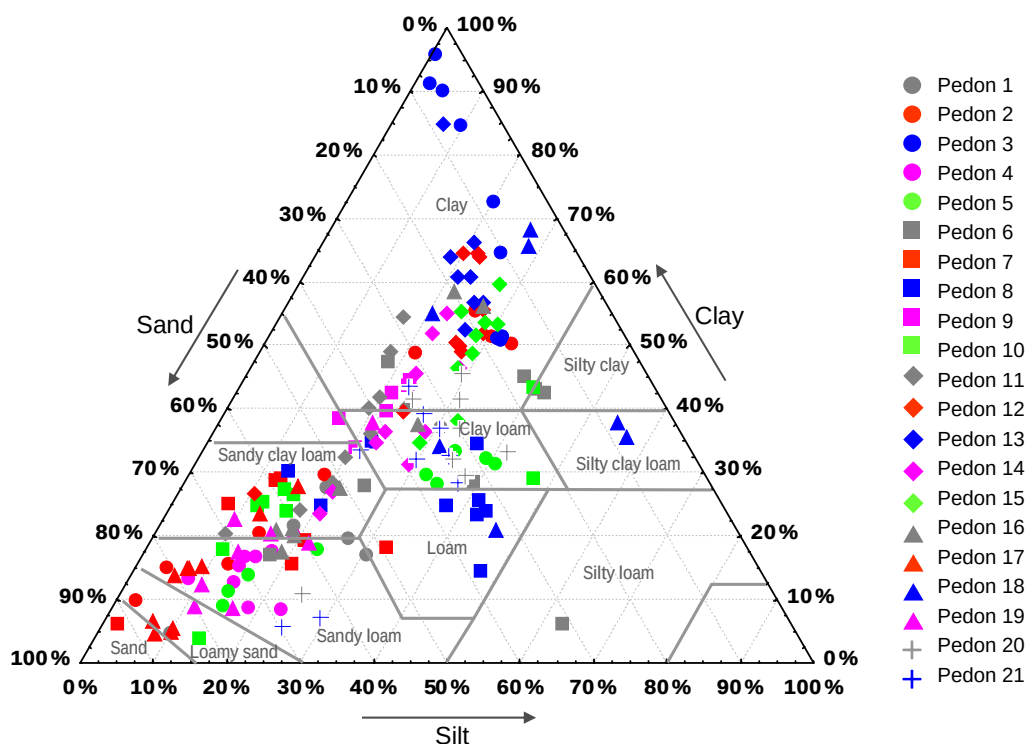


Figure 8 Textural classes of the 2 mm fraction of salt affected soils.

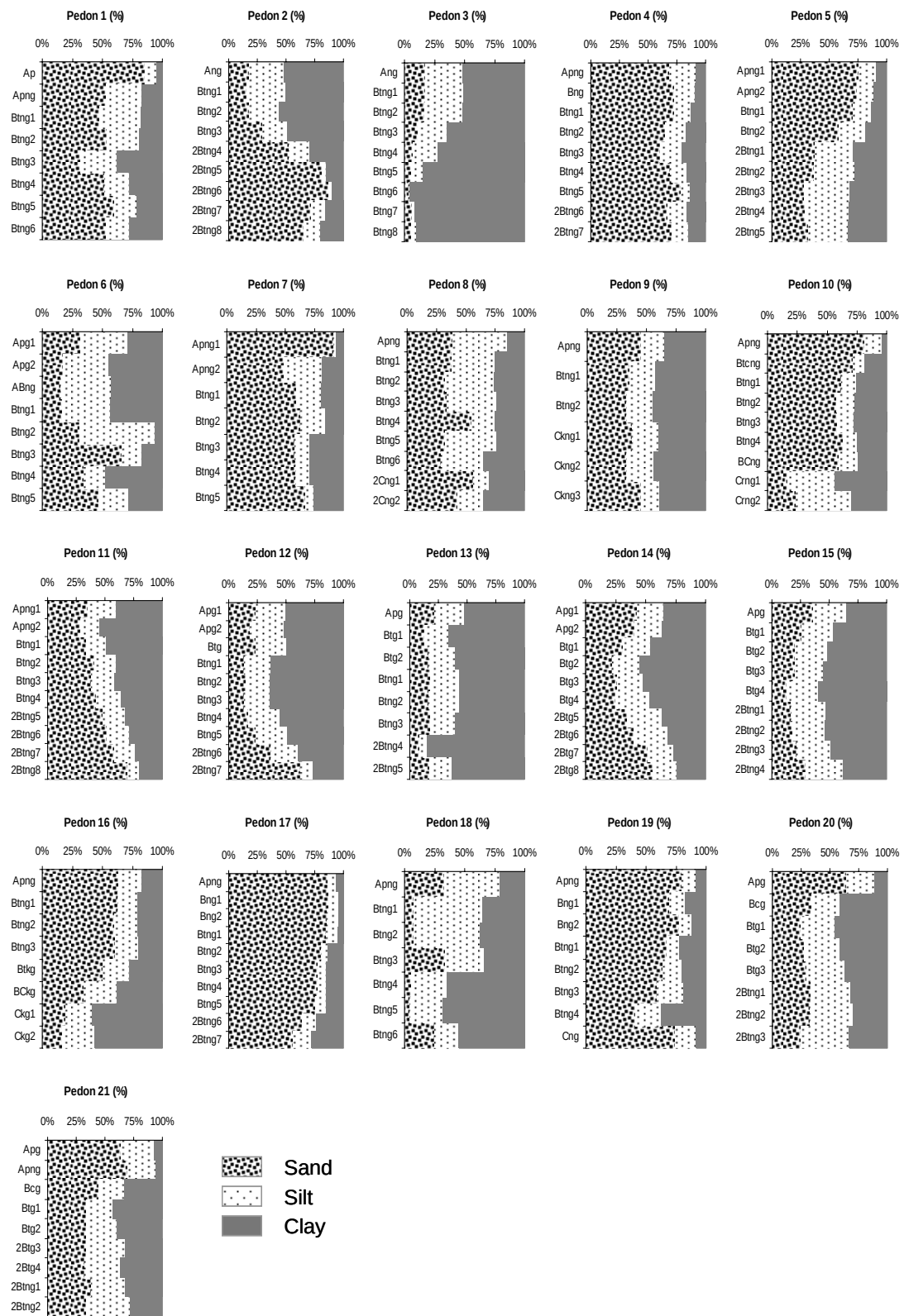


Figure 9 Particle size distribution profile of salt affected soils.

The bulk density values of these salt affected soils are moderately high to very high ranging from 1.51-2.49 Mg m^{-3} (Figure 10). The bulk density does not show a significant relationship with any soil property. The surface soils tend to have lower bulk density values than subsoils, probably as a result of higher organic matter contents and greater biological activity.

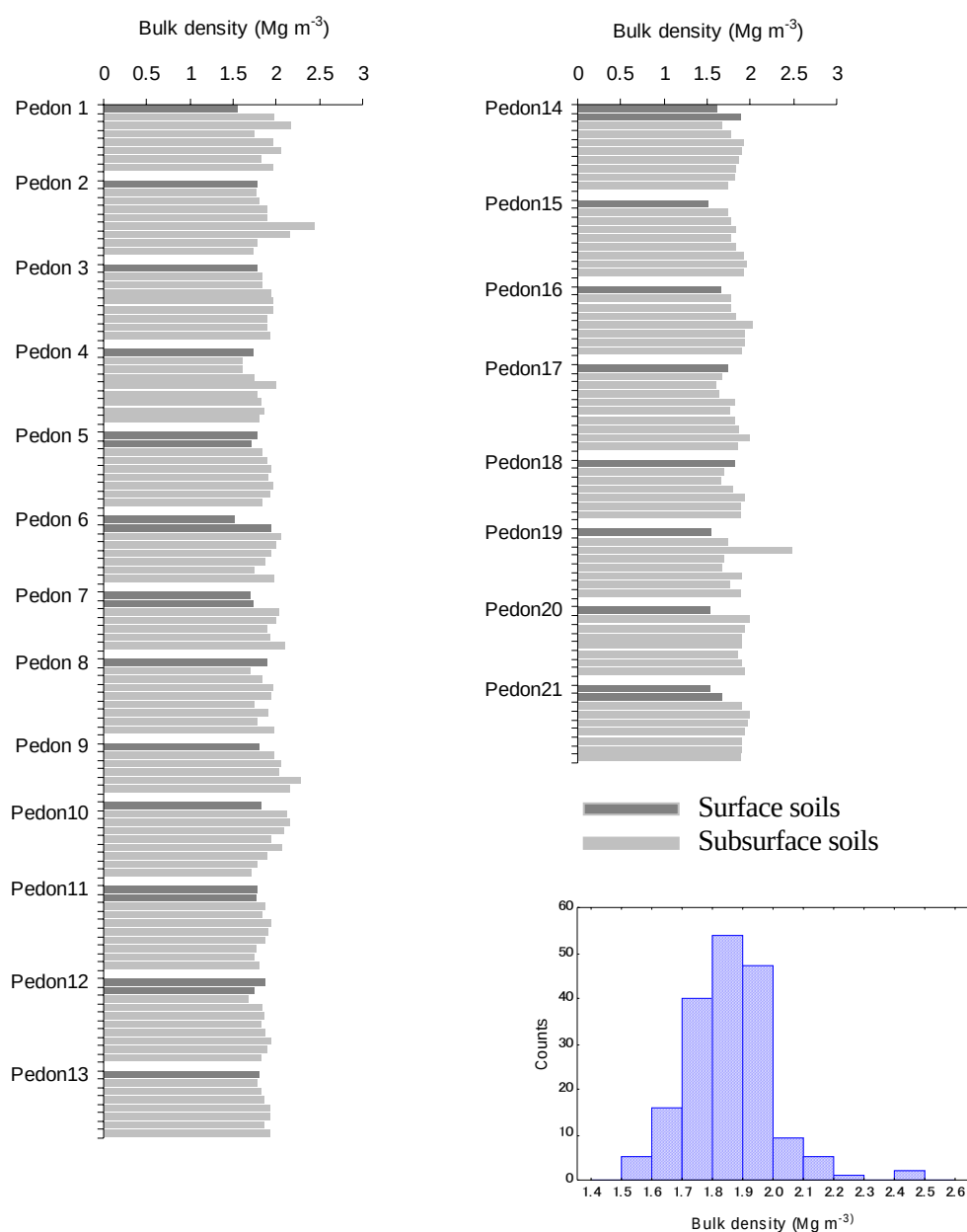


Figure 10 Bulk density of salt affected soils with samples arranged in horizon order and the frequency distribution of bulk density values.

However, the high bulk density of these soils can be a combination of the intensive agricultural practices, land use changes, high content of sodium as sodium can restrict soil particle aggregation and compaction caused by weight of the overlying layers. In addition, increasing clay content by illuviation causes clay particles to partially fill the spaces between the large particles which causes higher bulk density in the subsoils.

Hydraulic conductivity values of these soils range from 0.001-19620.00 cm hr^{-1} as given in the Appendix Table 1. Most soils have moderately slow to very slow (Figure 11) which tend to decrease with increasing bulk density. The very rapid hydraulic conductivity (value $> 25.00 \text{ cm hr}^{-1}$) is related to sand to loamy sand soil textures.

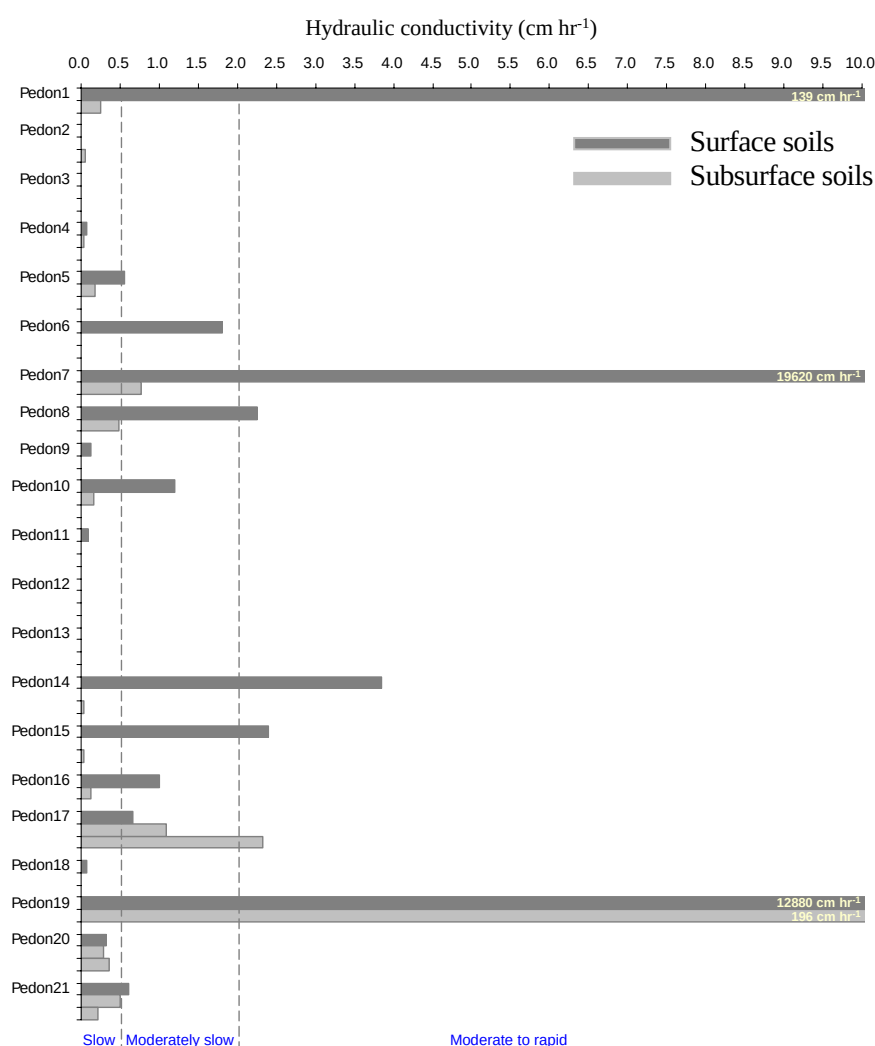


Figure 11 The graph showing the hydraulic conductivity of salt affected soils.

Chemical Properties

Chemical properties of salt affected soils are given in the Appendix Table 2.

The organic matter contents in these soils are very low to medium. The highest organic matter content is in the surface soils and it tends to decrease with depth (Figure 12a). This condition is normal for well developed soils (Buol *et al.*, 2003; Soil Survey Staff, 2006). The higher organic matter content for some soils is interpreted as the effect of their environmental conditions (i.e. (riverine) alluvium, flood plain) and present land use where paddy field conditions contribute organic matter to the surface and subsurface soils.

Soil pH in water of salt affected soils is generally high especially in subsurface horizons (Figure 12b). These soils can be divided into three groups which are acid, neutral and slightly alkaline salt affected soils (Soil Survey Division Staff, 1993). The very high pH values are largely due to the hydrolysis of sodium carbonate as occurs in sodic soils (Seelig, 2000; Brady and Weil, 2007). The low pH values of soils are consistent with the pH values of tropical soils that experience leaching (van Wambeke, 1992). The extractable acidity of soils ranges from low to high and relates to soil pH ($R^2 = 0.42$) (Figure 12c, d). High extractable acidity indicates highly leaching conditions (Cahn *et al.*, 1993; Buol *et al.*, 2003).

The sum of exchangeable bases of these soils is generally medium to low (Figure 13). Na is a dominant exchangeable base and its value ranges from 0.01-124.17 cmol kg⁻¹. The high value of exchangeable bases in some soils are probably caused by the geomorphic position which is a lower part of the soil system which receive bases from the Khok Kroat Formation including calcareous rocks (Geological Survey Division Staff, 1985) for Pedon 3 and the influence of parent materials that contains high level of bases for Pedons 8, 9 and 10. The highest values of Na in the transitional horizon to weathered rock of Pedon 10 indicate that the residual layer is a source of salt in this region.

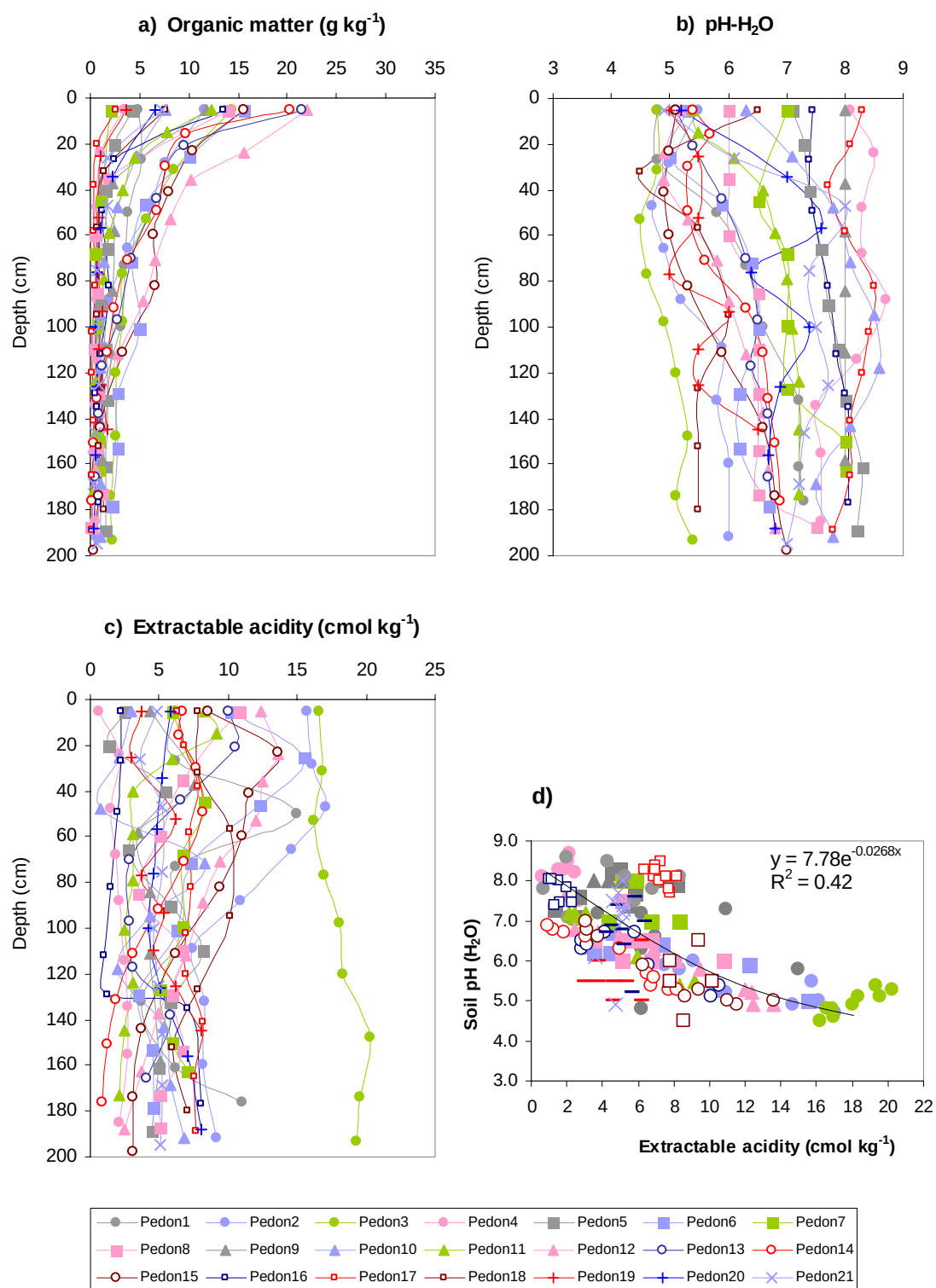


Figure 12 Depth variation and relationships for some chemical properties of salt affected soils.

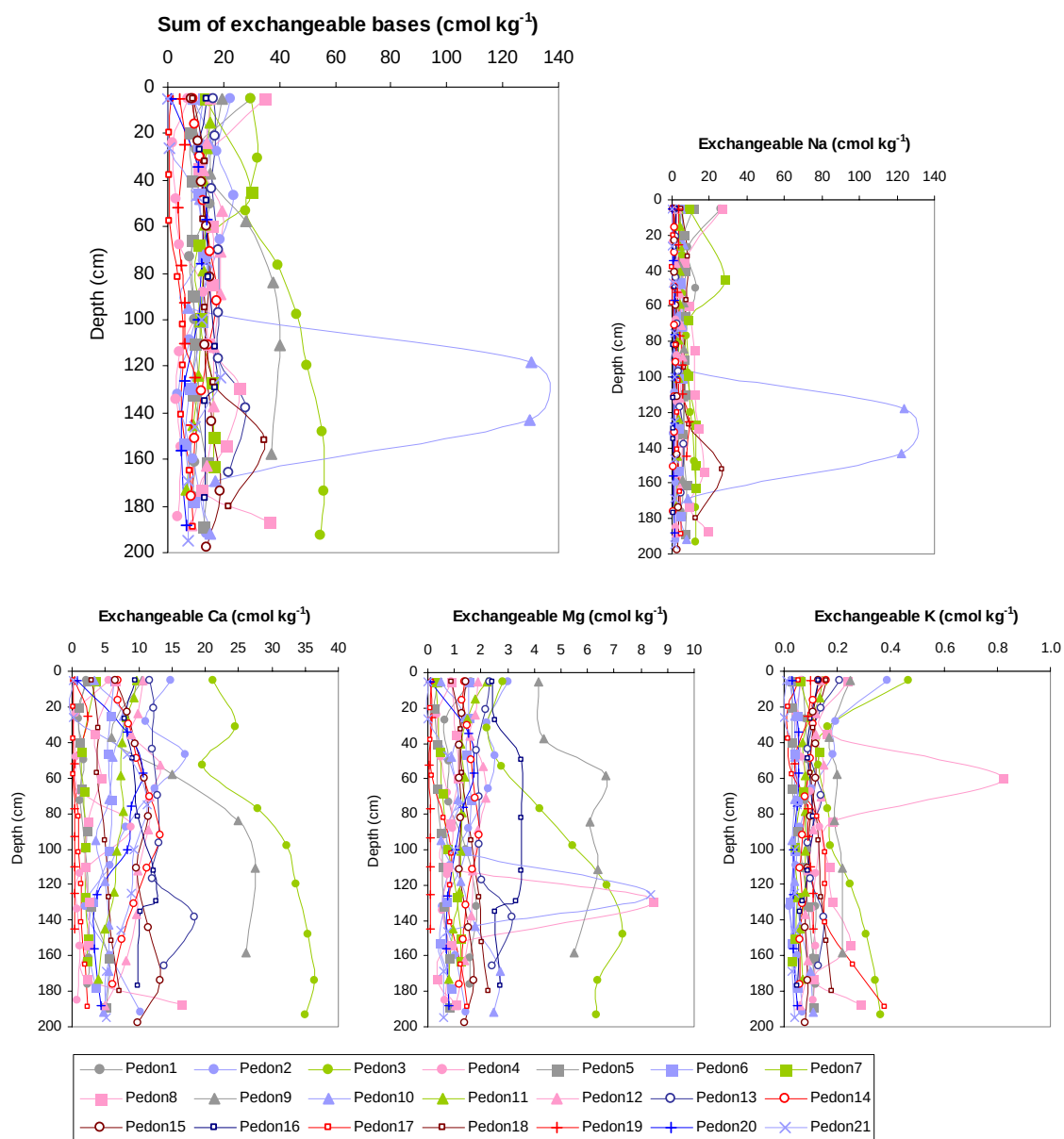


Figure 13 Depth variation for exchangeable bases of salt affected soils.

The CEC of these soils varies from low to high ranging from 0.4-46.24 cmol kg^{-1} (Figure 14a). The very low CEC values are for sandy soils especially Pedons 4 and 17. The variation in CEC closely reflects the clay contents of the soils ($R^2 = 0.45$) (Figure 14b). Higher CEC values in some of these soils reflects the presence of minor amounts of smectite and illite. All soils have high base saturation percentage of more than 35 percent (Figure 14c) except in the upper part of Pedons 17, 20 and 21 due to high sand content and low EC.

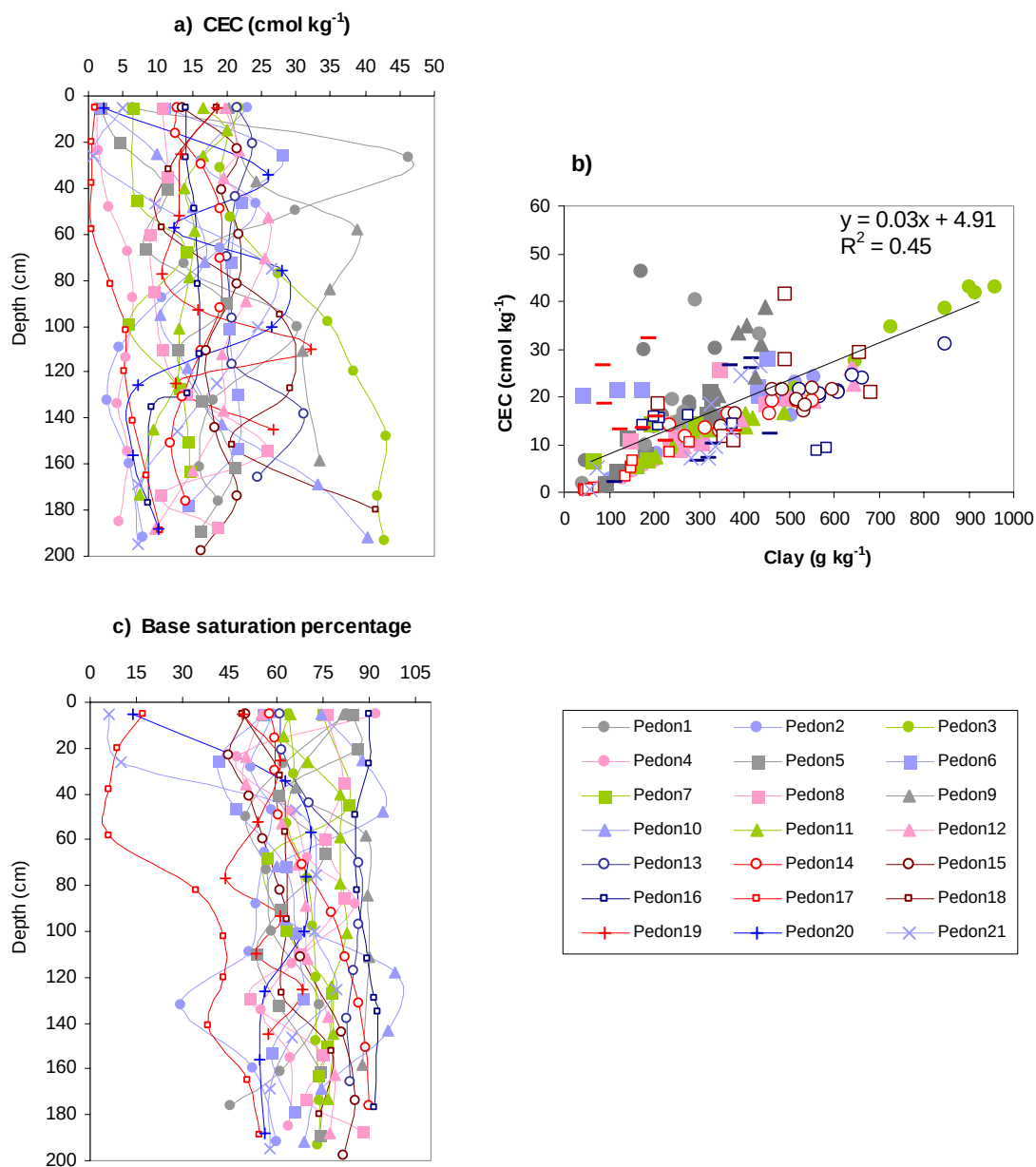


Figure 14 Depth variation of CEC and relationships between CEC and clay content for salt affected soils.

According to the criteria for salt affected soils of Soil Survey Staff (2006), Most soils are saline-sodic soils except the saline soils Pedons 14 and 16 and sodic soils Pedons 20 and 21 (Figure 15). Most soils have the highest EC values in the surface horizon. This may be a result of upward capillary movement of saline water in the dry season due to high evaporation (Northey *et al.*, 2006; Zwikel *et al.*, 2007).

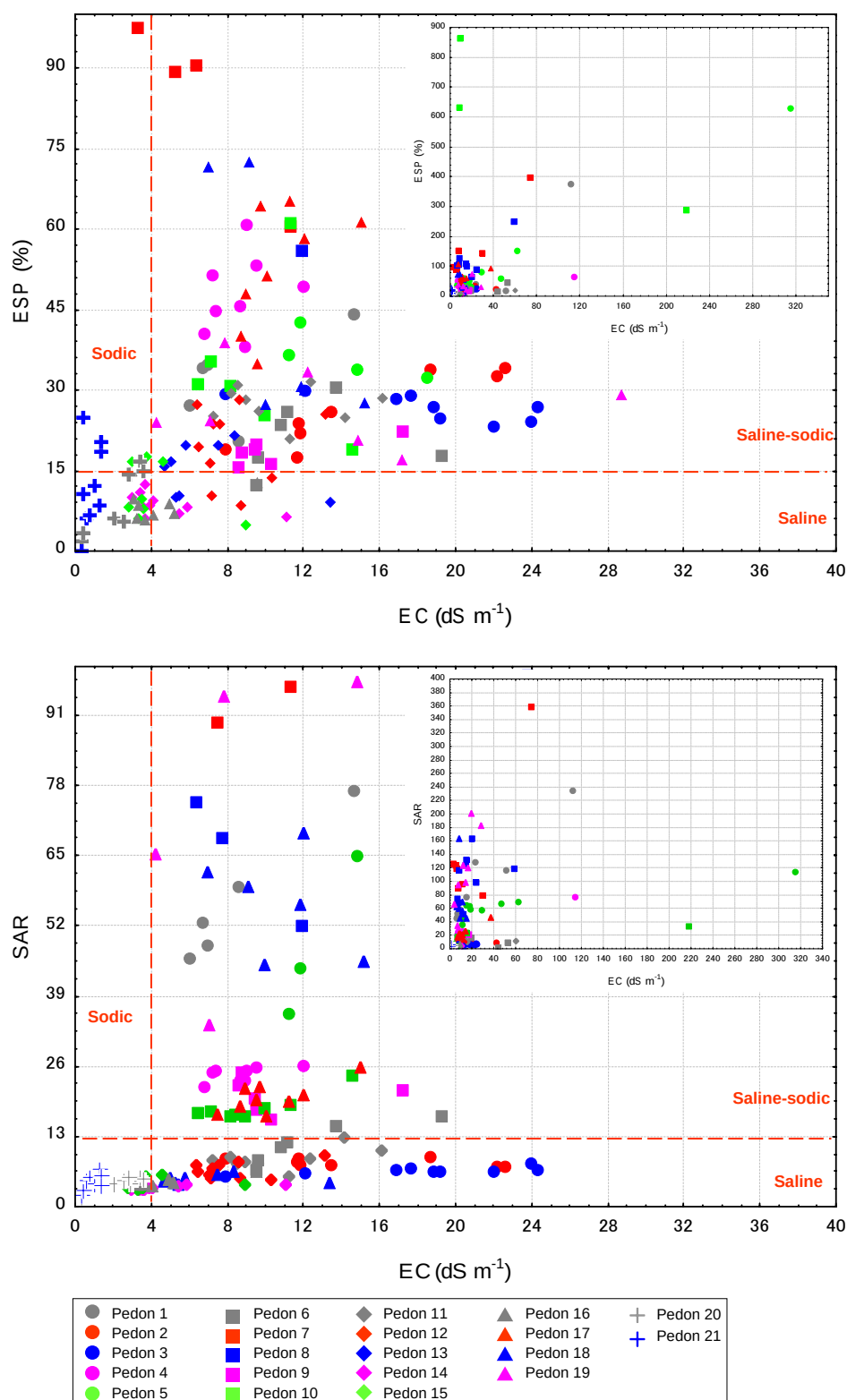


Figure 15 Scatter plots of electrical conductivity (EC) versus exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) of the soils.

Mineralogical Properties

The semiquantitative mineralogy of clay and silt fractions of salt affected soils for this study is given in Table 4 and some XRD patterns illustrating soil mineralogy are shown in Figure 16. Most soils have a mixed mineralogy where kaolinite and smectite are major minerals in the clay fraction with some illite and quartz.

Kaolinite is a dominant mineral in the clay fraction with small amounts of smectite and trace of illite for Pedons 11-15, 18, 20 and 21. Quartz is a dominant mineral in the clay fraction with small amounts of kaolinite and smectite in the upper horizons of Pedons 5, 6 and 17. Traces of chlorite are present in the lower part of Pedon 10 associated with weathered parent rock.

In the silt fraction, quartz is a dominant mineral due to it being a resistant mineral. Traces of feldspar occur in some soils and higher amounts of feldspar are associated with the parent material layer (C horizon). Trace of mica and small amounts of calcite are present in the C horizon of Pedons 8, 9 and 16 respectively.

Most soils are on the terrace and erosional plain have experienced leaching of Si and basic cations in the tropical climate with high rainfall particularly soils in the east of the basin. This condition favors formation of kaolinite (Tardy *et al.*, 1973; Suddhiprakarn *et al.*, 1985; Trakoonyingcharoen *et al.*, 2006). The presence of much quartz in the clay fraction may be inherited from parent materials derived from highly weathered sandstone and siltstone of the Mahasarakham Formation and quartz in silt fraction can also be transferred to the clay fraction by weathering and hydrolysis reactions under a tropical climate (Suddhiprakarn, 1978; Drees *et al.*, 1989; Yoshinaga *et al.*, 1989). The deep soils exhibit clay accumulation in subsoils indicating past leaching conditions and soil development under a wetter climate than at present. In contrast, the presence of salts and carbonate materials in these soils implies recent limited of leaching and dryer conditions (Dultz and Kuhn, 2005).

Table 4 Semi-quantitative mineralogy of clay and silt fractions of salt affected soils.

Horizon	Depth (cm)	^A Clay fraction					^B Silt fraction			
		Kao	Sme	Ill	Int	Chl	Qtz	Qtz	Fel	Other
<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic (P1)</i>										
Apn	0-15	xxx	tr	x	nd	nd	x	xxxx	nd	nd
Btng1	40-50/60	xxx	tr	x	nd	nd	tr	xxxx	nd	nd
Btng3	87-114	xxx	tr	x	nd	nd	x	xxxx	nd	nd
Btng5	150-172	xxx	tr	x	nd	nd	tr	xxxx	nd	nd
<i>Vertic Natraqualf, fine-loamy, mixed, isohyperthermic (P2)</i>										
Ang	0-19	xx	xx	x	nd	nd	xx	xxxx	nd	nd
Btng1	19-38	xxx	xx	x	nd	nd	xx	xxxx	nd	nd
Btng3	56-77	xxxx	x	tr	nd	nd	xx	xxxx	nd	nd
2Btng6	119-146	xx	xx	tr	nd	nd	xx	xxxx	nd	nd
<i>Vertic Natraqualf, fine-loamy, mixed, semiactive, isohyperthermic (P3)</i>										
Ang	0-21	xx	xx	x	nd	nd	xxx	xxxx	nd	nd
Btng1	21-41	xxx	xx	tr	nd	nd	xx	xxxx	nd	nd
Btng5	108-132	xx	xx	x	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic (P4)</i>										
Apng	0-12	xx	x	nd	nd	nd	xxx	xxxx	nd	nd
Bng	12-37	xxx	nd	nd	xx	nd	xx	xxxx	nd	nd
Btng2	60-76	xxxx	x	nd	nd	nd	x	xxxx	nd	nd
2Btng6	140-170	xx	xx	x	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf, fine-loamy, mixed, isohyperthermic (P5)</i>										
Apng1	0-28	x	tr	nd	nd	nd	xxxx	xxxx	nd	nd
Btng1	28-53	x	x	nd	nd	nd	xxx	xxxx	nd	nd
2Btng1	80-100	xx	xx	x	nd	nd	xx	xxxx	tr	nd
2Btng5	178-200	xx	xx	x	nd	nd	x	xxxx	tr	nd
<i>Typic Natraqualf; fine, mixed, isohyperthermic (P6)</i>										
Apng1	0-32/36	x	x	nd	nd	nd	xxx	xxxx	tr	nd
ABng	36-57	x	xx	nd	nd	nd	xxx	xxxx	tr	nd
Btng2	87-115	x	xx	nd	nd	nd	xxx	xxxx	tr	nd
Btng5	162-200	x	xx	tr	nd	nd	xxx	xxxx	tr	nd
<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic (P7)</i>										
Apng1	0-20/35	xx	tr	tr	nd	nd	x	xxxx	tr	nd
Btng1	55-76/81	xx	xx	tr	nd	nd	x	xxxx	nd	nd
Btng3	118- 130/137	xx	xxx	tr	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic (P8)</i>										
Apng	0-20	x	xx	xx	nd	nd	x	xxxx	tr	nd
Btng1	20-45/50	x	xx	xx	nd	nd	x	xxxx	tr	nd
Btng3	70- 95/100	x	xxx	xx	nd	nd	x	xxxx	tr	nd
2Cng1	170- 172/175	x	xxx	xx	nd	nd	x	xxxx	x	M (x)
<i>Typic Natraqualf; fine, mixed, isohyperthermic (P9)</i>										
Apng	0-13/15	xx	x	xx	nd	nd	x	xxxx	nd	nd
Btng1	15-37/40	xx	x	xx	nd	nd	x	xxxx	nd	nd
2Ckng2	96- 123/126	xx	x	xx	nd	nd	tr	xxxx	nd	M (tr)

Table 4 (Continued)

Horizon	Depth (cm)	^A Clay fraction					^B Silt fraction			
		Kao	Sme	Ill	Int	Chl	Qtz	Qtz	Fel	Other
<i>Typic Natraqualf; loamy-skeletal, mixed, isohyperthermic (P10)</i>										
Apng	0-12/15	x	x	nd	nd	nd	xxx	xxxx	tr	nd
Btcng	15-32/36	xx	xxx	nd	tr	nd	x	xxxx	tr	nd
Btng2	60-85	x	x	tr	nd	tr	x	xxxx	tr	nd
BCng	130-156	x	xx	tr	nd	tr	x	xxxx	x	nd
Crng	182-203	x	xx	x	nd	tr	x	xxxx	x	nd
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P11)</i>										
Apng1	0-10	xxxx	xx	tr	nd	nd	x	xxxx	nd	nd
Btng1	20-33	xxxx	x	tr	nd	nd	tr	xxxx	nd	nd
Btng3	48-70	xxxx	nd	tr	xx	xx	tr	xxxx	nd	nd
2Btng7	135-156	xxx	xx	x	nd	nd	x	xxxx	tr	nd
<i>Typic Natraqualf; very fine, kaolinitic, isohyperthermic (P12)</i>										
Apg1	0-18	xxxx	x	tr	nd	nd	x	xxxx	tr	nd
Btg	30-42	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
Btng1	42-53/64	xxxx	nd	tr	xx	nd	x	xxxx	nd	nd
Btng4	100-124	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
2Btng6	151-176	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P13)</i>										
Apg	0-11	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
Btg1	11-32	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
Btng1	56-65/85	xxxx	x	nd	nd	nd	tr	xxxx	nd	nd
2Btng4	124-152	xxxx	x	tr	nd	nd	tr	xxxx	nd	nd
<i>Typic Endoaqualf; fine, kaolinitic, isohyperthermic (P14)</i>										
Apg1	0-10	xxxx	x	tr	nd	nd	x	xxxx	tr	nd
Btg1	22-38	xxxx	x	tr	nd	nd	x	xxxx	tr	nd
Btg4	83-102	xxxx	xx	tr	nd	nd	tr	xxxx	tr	nd
2Btng5	102-121	xxxx	xx	tr	nd	nd	x	xxxx	tr	nd
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P15)</i>										
Apg	0-16	xxxx	x	tr	nd	nd	x	xxxx	nd	nd
Btg2	31-52	xxx	nd	tr	xx	nd	x	xxxx	nd	nd
Btg4	69-95	xxxx	nd	tr	xx	nd	x	xxxx	nd	nd
2Btng4	161-187	xxxx	xx	tr	nd	nd	x	xxxx	nd	nd
<i>Aeric Kandiaqualf; fine-loamy, mixed, isohyperhthermic (P16)</i>										
Apng	0-18	tr	xxx	tr	nd	nd	tr	xxxx	tr	nd
Btg2	36-63	tr	xxx	tr	nd	nd	tr	xxxx	tr	nd
Btkg	101-123	tr	xxxx	tr	nd	nd	tr	xxx	x	C (tr)
BCkg	123-135	tr	xxx	tr	nd	nd	tr	nd	nd	nd
Ckg1	135-195	tr	xxx	tr	nd	nd	tr	x	x	C(xxx)
<i>Typic Natraqualf; sandy, silicious, isohyperthermic (P17)</i>										
Apng	0-11	x	x	tr	nd	nd	xxxx	xxxx	nd	nd
Bng2	30-47	x	nd	tr	x	nd	xxxx	xxxx	nd	nd
Btng3	95-110	xxx	xx	tr	nd	nd	x	xxxx	nd	nd
2Btng6	153-178	x	x	xx	nd	nd	xx	xxxx	nd	nd

Table 4 (Continued)

Horizon	Depth (cm)	^A Clay fraction					^B Silt fraction			
		Kao	Sme	Ill	Int	Chl	Qtz	Qtz	Fel	Other
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P18)</i>										
Apng	0-20/23	xxxx	x	x	nd	nd	x	xxxx	nd	nd
Btng1	23-35/42	xxxx	xx	x	nd	nd	x	xxxx	nd	nd
Btng3	72-98/118	xxxx	xx	x	nd	nd	x	xxxx	nd	nd
Btng5	137- 162/168	xxxx	x	x	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic (P19)</i>										
Apng	0-13/16	xx	tr	x	nd	nd	x	xxxx	tr	nd
Bng1	16-35/37	xx	xx	x	nd	nd	x	xxxx	tr	nd
Btng1	68-86	xxx	xx	x	nd	nd	tr	xxxx	tr	nd
Btng3	100- 108/120	xx	xxx	x	nd	nd	tr	xxxx	tr	nd
Cng	131-160	xx	xxx	x	nd	nd	tr	xxxx	tr	nd
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P20)</i>										
Apg	0-15/23	xxxx	nd	nd	x	nd	x	xxxx	nd	nd
Bcg	23-46	xxxx	x	nd	nd	nd	tr	xxxx	nd	nd
Btg2	65-88	xxxx	nd	nd	x	nd	tr	xxxx	nd	nd
2Btng3	172-205	xxxx	tr	tr	nd	nd	x	xxxx	nd	nd
<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic (P21)</i>										
Apg	0-19/20	xxxx	nd	nd	x	nd	xx	xxxx	nd	nd
Bcg	42-54/63	xxxx	nd	nd	xx	nd	tr	xxxx	nd	nd
Btg2	87- 111/114	xxxx	x	nd	nd	nd	tr	xxxx	nd	nd
2Btg3	114-137	xxxx	x	nd	nd	nd	x	xxxx	nd	nd
2Btng1	155-183	xxxx	x	nd	nd	nd	x	xxxx	nd	nd

^{A, B} Kao = kaolinite, Sme = smectite, Int = interstratified 10Å and 14Å minerals,
 Ill = illite Chl = chlorite, Qtz = quartz, Fel = feldspar
 xxxx = dominant (> 60%), xxx = large (40 - 60%), xx = medium (20 - 40%),
 x = small (5-20%), tr = trace (< 5%), nd = not detected
 C = calcite, M = mica

The smectite in the C and/or BC horizons of soils (Pedons 8, 10, 16 and 19) may indicate that this mineral occurs in the weathered rocks. Alternatively, the abundance of smectite in the soils indicates high bases, poor drainage, a long period of saturation and low leaching conditions under a tropical savanna climate (Borchardt, 1989; Wilson, 1999). Furthermore, the occurrence of salinization in the soils creates an alkaline condition inducing silica dissolution (Dove and Crerar, 1990; Van Breemen and Buurman, 2002). This condition can decrease the size of quartz grains to clay size and form smectite by resilication of kaolinite (Tan, 1982; Wongpokhom *et al.*, 2008) as

indicated by the presence of interstratified mineral in some soils (Figure 17) which may be an intermediate mineral in the alteration of kaolinite to smectite.

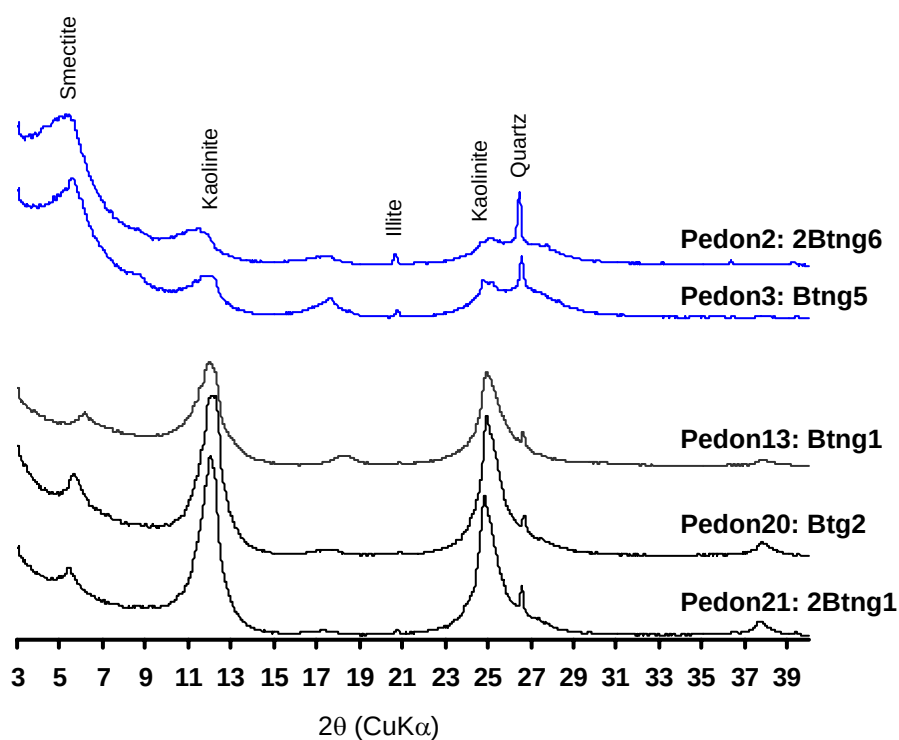


Figure 16 XRD patterns of the oriented clay fraction of some salt affected soils showing the major clay minerals.

Mineralogical analysis results for salt crust in these soils show that halite is the major salt (Figure18).

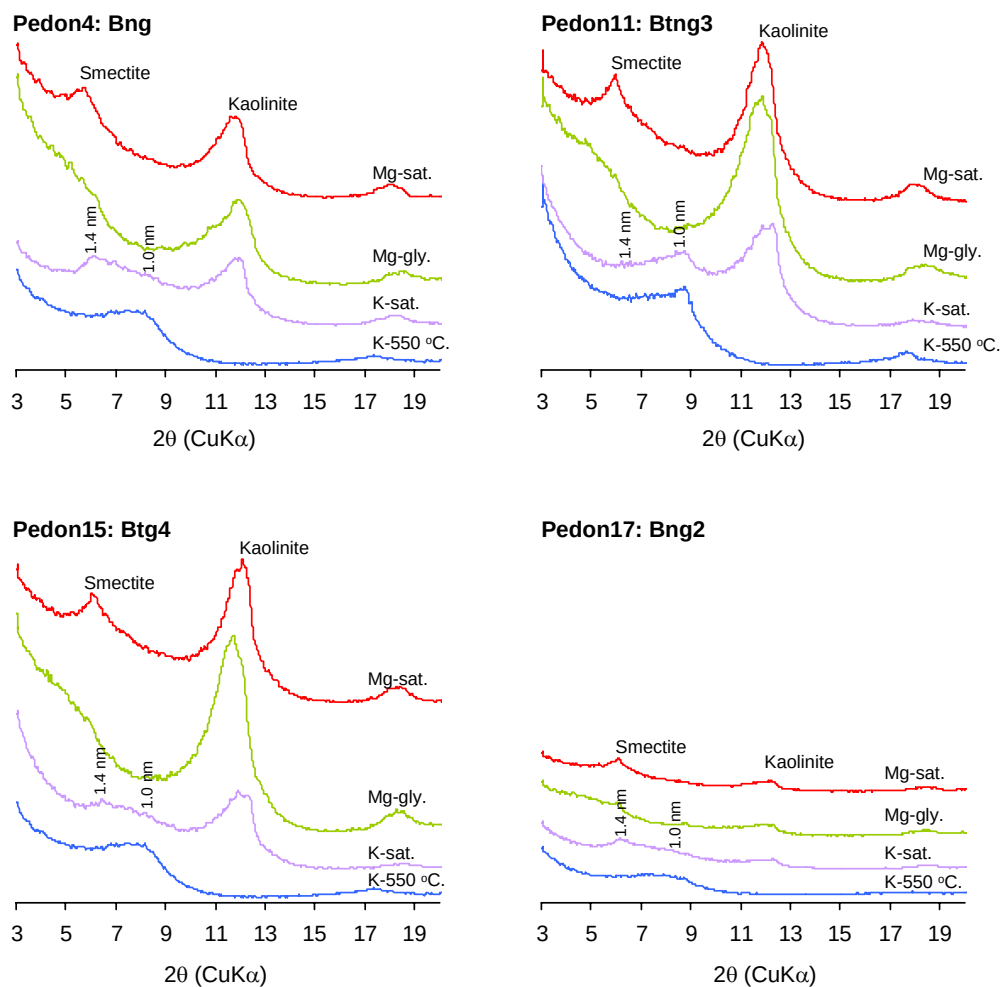


Figure 17 Some XRD patterns of the oriented clay fraction of salt affected soils showing the interstratified mineral which has basal spacings of 1.0nm and 1.4 nm.

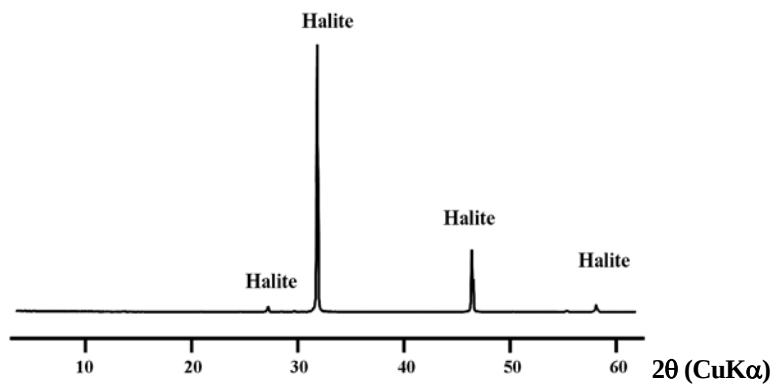


Figure 18 XRD pattern of the salt crust on the surface of a salt affected soil.

Micromorphological Properties

The main micromorphological features of the salt affected soils are listed in Table 5. The microstructures of these salt affected soils reflect differences in texture. The fine textured soils have common channel, vughy and crack structures and a few moderately to weakly developed subangular blocky structure (Figures 19 and 20). Pores are mainly channels, vughs and a mixture of planar voids and vughs. Compact grain, intergrain and bridge grain structures are common in coarse textured soils (Figures 21 and 22). Pores are mainly simple packing voids with frequent vughs and a few vesicles. Soil porosity consists of mainly macropores. Mesopores and micropore dominate in the fine textured soils (Figures 19d and 20d).

The upper parts of all soil profiles generally have coarser materials than do the subsoils. The coarser mineral materials are mainly quartz skeletal grains present in various amounts and their sizes range from medium sand to silt. Grains shapes vary from subangular to subrounded frequent runi-quartz and a few metamorphic quartz grains that indicate a mixture of long and short distance water transported materials. The lower parts of soil profiles are dominated by fine materials. Some horizons with poorly sorted quartz and few runi-quartz indicate residual material (Bullock *et al.*, 1985; Buol *et al.*, 2003; Suddhiprakarn and Kheoruenromne, 1998). The fine fraction consists of variously colored clay to fine silt materials with a dotted appearance. Organic pigments are common in topsoil materials.

Clay as a coating on the walls of voids and quartz and bridged grains is present in all subsoils which is indicative of an argillic-natric horizon (Buol *et al.*, 2003). Most residual layers, particularly Pedons 5, 10, 20 and 21, have clay mixed with iron oxide as mottles and coatings on the wall of voids and some infillings. Amorphous pedofeatures are manganiferous impregnated nodules and impregnative s-matrix which are present in most soils.

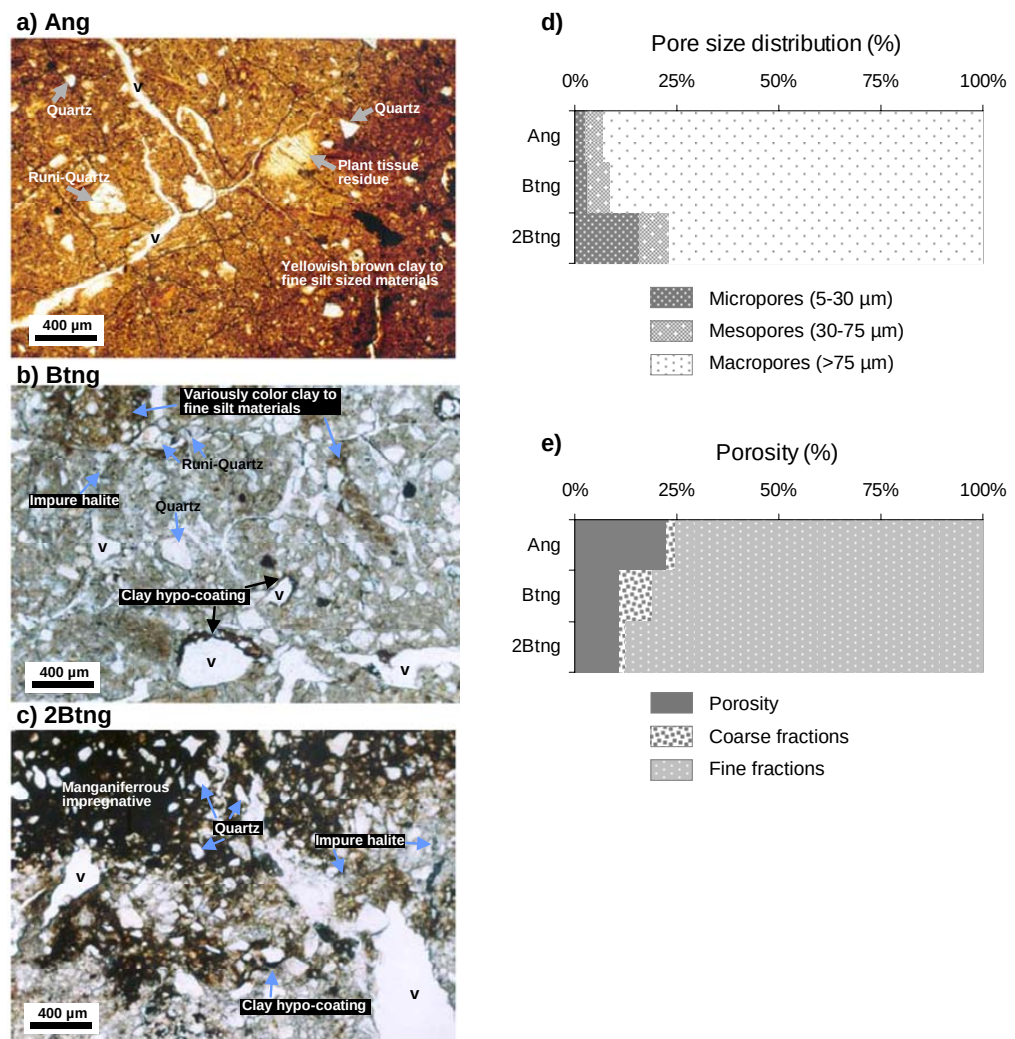


Figure 19 Optical micrograph of a representative fine textured salt affected Vertic Natraqualf, fine-loamy showing moderately to strongly developed angular blocky structure with mainly accommodated planar voids, clay hypo-coatings on the wall of voids, impure halite coated on the wall of voids, manganiferous impregnative s-matrix (a, b, and c) and the relative proportions of micropores, mesopores and macropores (d) and soil porosity (e) obtained by image analysis of SEM images of thin sections.

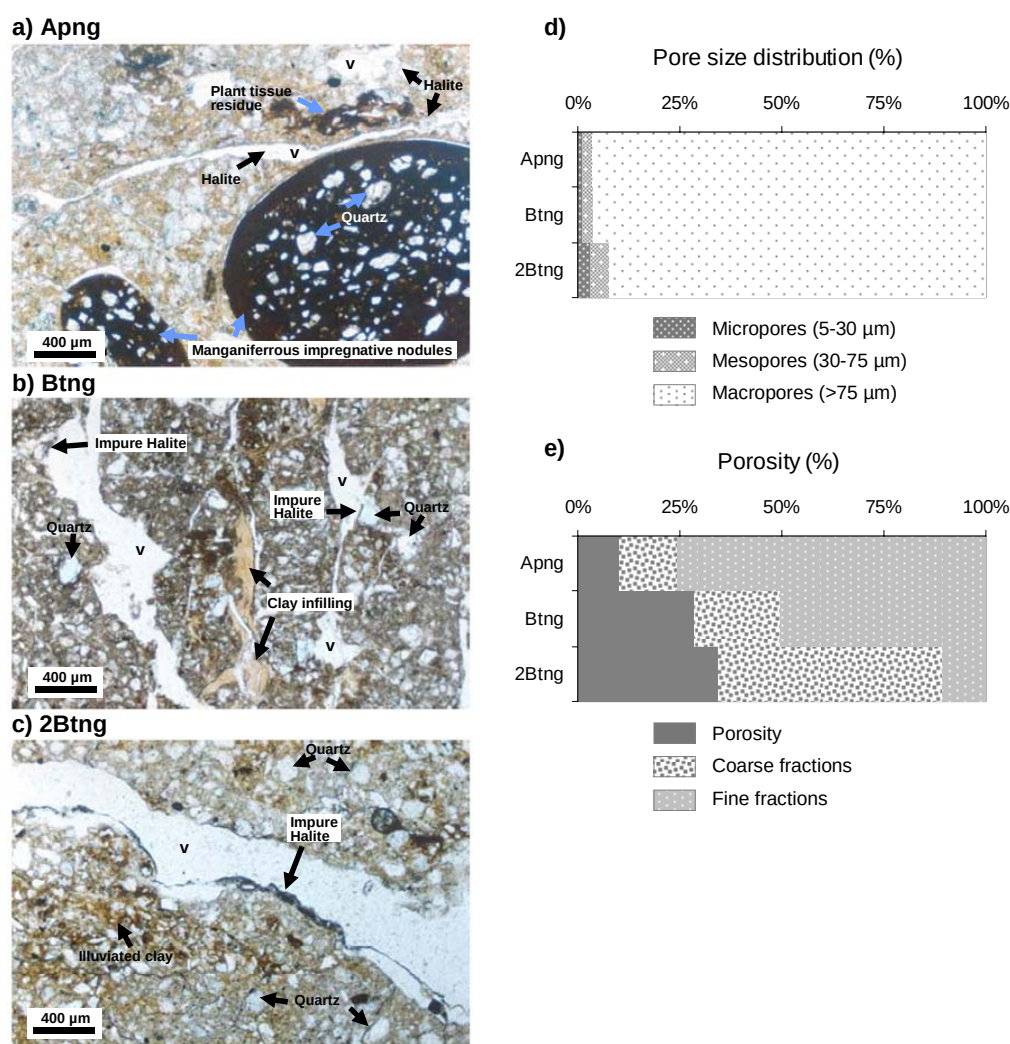


Figure 20 Optical micrograph of a representative fine textured salt affected Typic Natraqualf, fine showing channel structure mixed with weakly to moderately developed subangular blocky structure, pale yellow and yellowish brown illuviated clay as a clay coating on the wall of voids and infilling, microcrystalline/ impure halite coating on the wall of voids (a, b and c) and the relative proportions of micropores, mesopores and macropores (d) and soil porosity (e) obtained by image analysis of SEM images of thin sections.

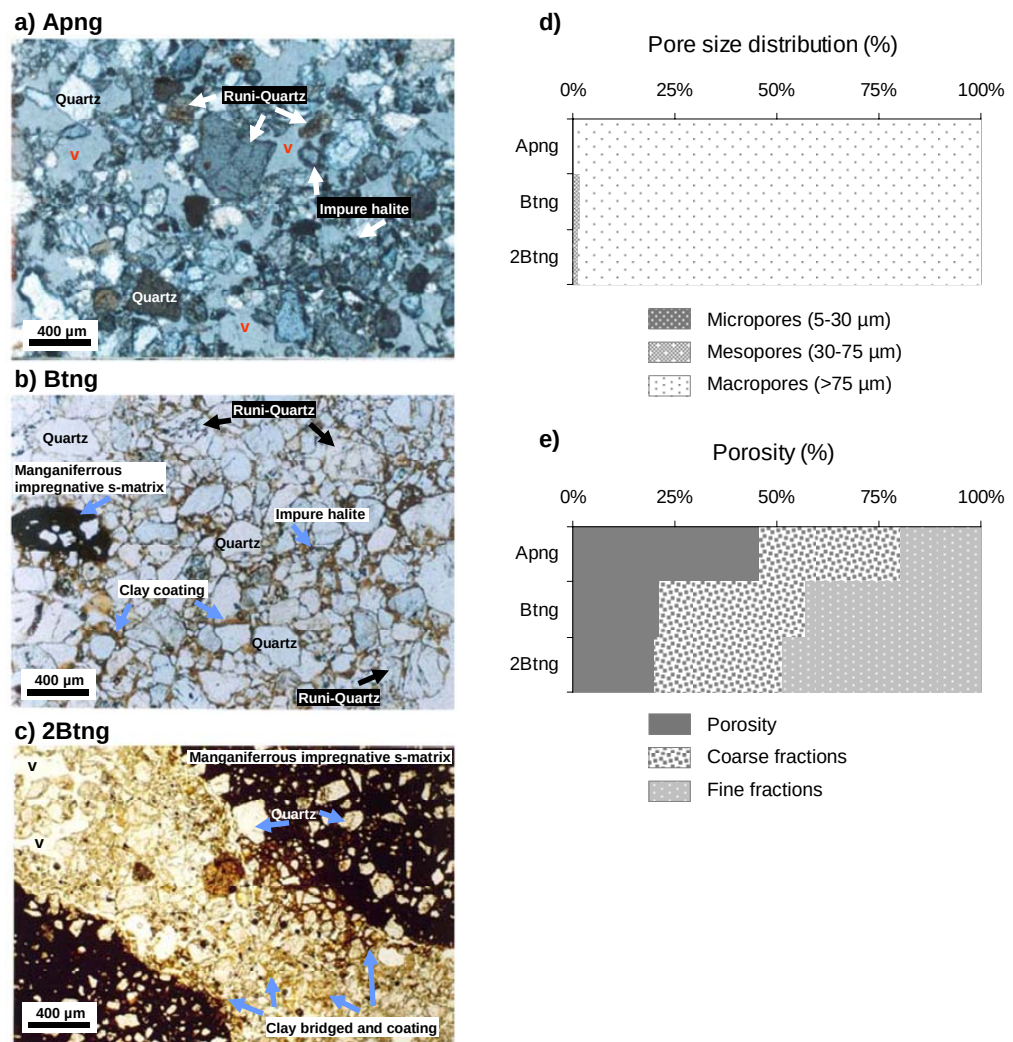


Figure 21 Optical micrograph of a representative coarse textured salt affected Typic Natraqualf, coarse-loamy showing compact grain and bridge grain structures, impure halite in simple packing voids, light yellow and yellowish brown to dark brown clay mixed with iron oxide coatings on quartz grains and the walls of voids (a, b and c) and the relative proportions of micropores, mesopores and macropores (d) and soil porosity (e) obtained by image analysis of SEM images of thin sections.

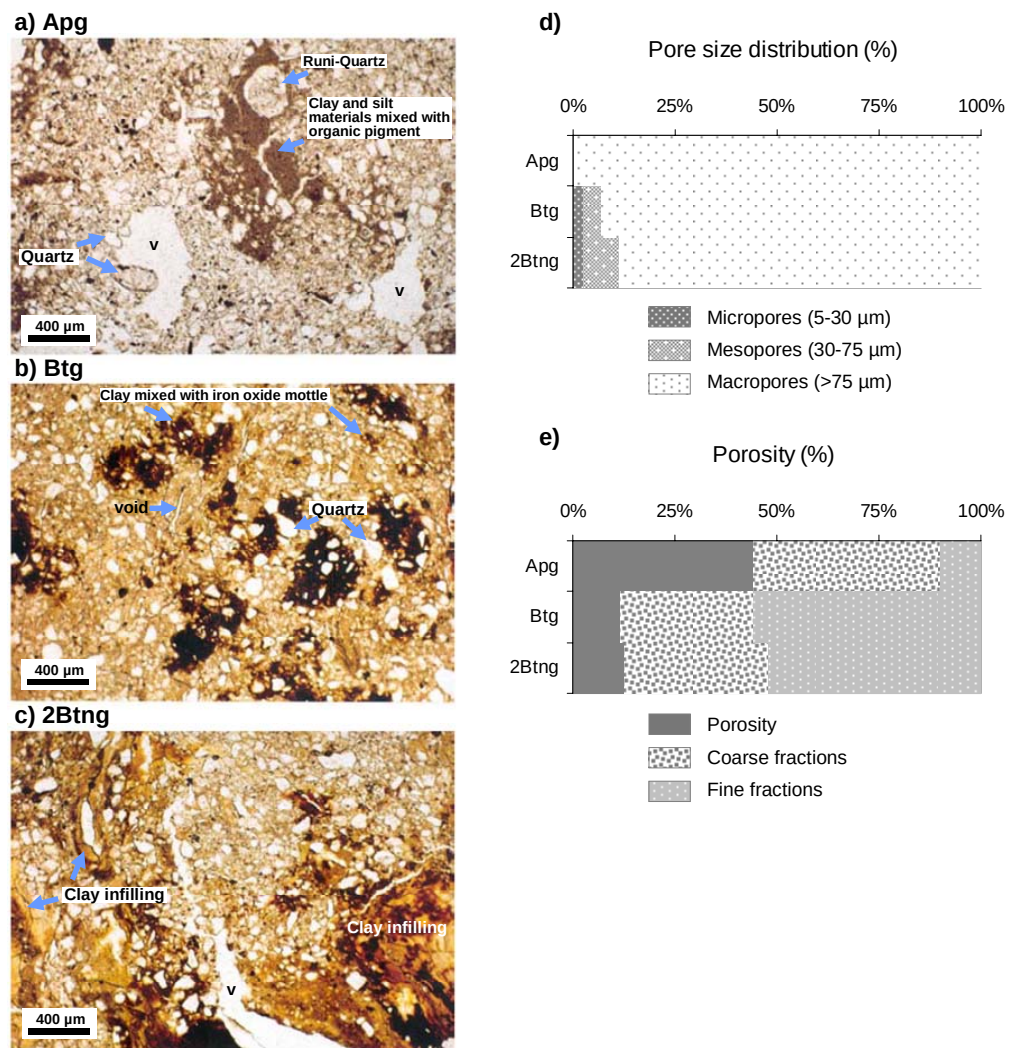


Figure 22 Optical micrograph of a representative coarse over fine textured salt affected Typic Natraqualf, fine showing vughy structure and crack structure, yellowish brown to strong brown clay mixed with iron oxide mottles of various sizes and shapes and some coatings on the wall of voids and infillings (a,b and c) and the relative proportions of micropores, mesopores and macropores (d) and soil porosity (e) obtained by image analysis of SEM images of thin sections.

Impure halite coating on the wall of voids is a common crystalline pedofeatures and can be found in all soils except Pedons 16, 20 and 21. This shows that most of these soils are salt affected. Many soils (Pedons 1-5, 10 and 17) have high amount of impure halite in the profiles and the highest content is in the surface soils

indicating severely salt affected soils. Some soils (Pedons 5, 10 and 17) show abundant clay mixed with microcrystalline halite accumulating as mottles in the residual layer (2Btng) (Figure 23a, b, c) indicating that they are more salt affected than other soils. Furthermore, the high salt content in residual layer especially in the weathered rock layer indicates this layer as the main source of salt. The salt accumulation present at different horizons and depths is related to the conditions of soils that control vertical salt movement in the soil profiles. Halite is not present in Pedons 16, 20 and 21 implying that they are slightly salt affected soils. Prismatic gypsum clusters are present in some horizons of Pedon 12 (Figure 23d). Carbonate materials (Figure 24b, c) are in some horizons of Pedons 2 (2Btng), 4 (2Btng), 8 (Btng), 9 (Ckng), 11 (Apng) and 16 (BCkng) indicating current drier conditions.

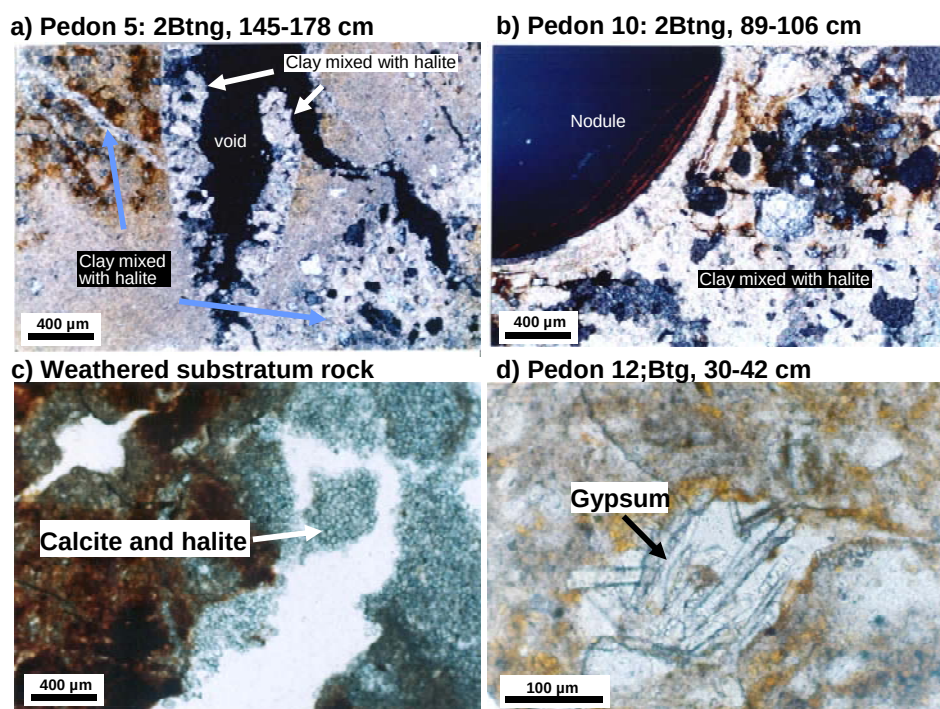


Figure 23 Optical micrograph of salt affected soils showing clay mixed with microcrystalline halite and iron oxides mottles, infilling and coating on the wall of voids, quartz grains and nodules in the residual layer (a and b), calcite and halite in weathered substratum rock in Pedon 17 (c) and prismatic gypsum (d).

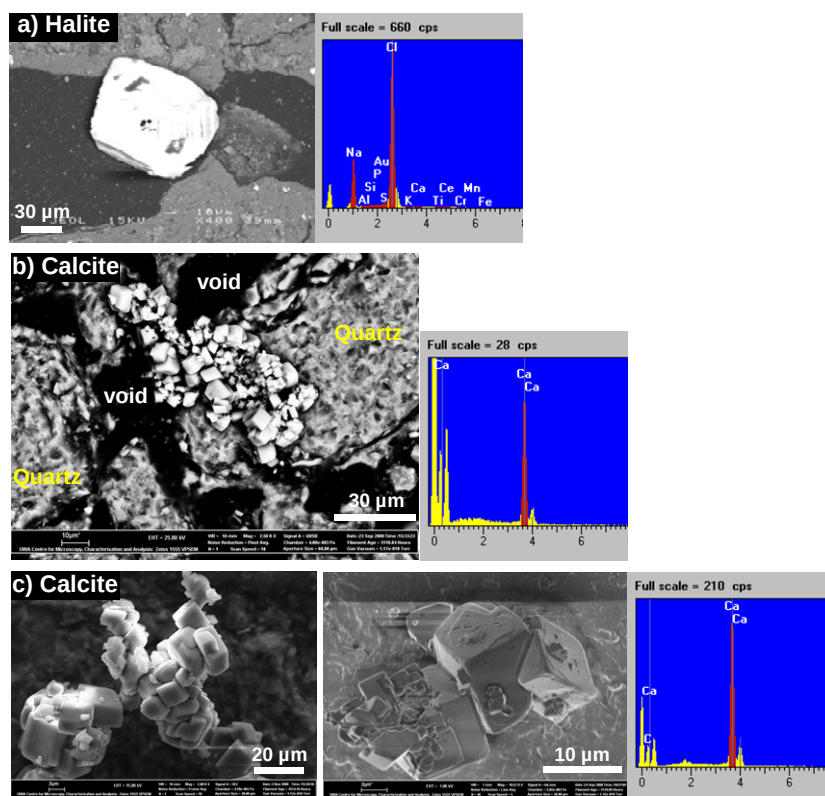


Figure 24 SEM image and EDS spectrum showing halite crystals in a void in Apng of Pedon 3 (a), calcite crystals on the walls of voids and quartz grains in 2Btng of Pedon 4 (b) and calcite morphology at high magnification (mag. 2×10^3 – 11×10^3 x) in Apng of Pedon 11.

Total analysis using an X-ray microprobe was used to identify the composition of some pedological features (soil matrix, illuviated clay, mottle and nodule) in the Ap, Bt and 2Bt horizons of representative salt affected soils (Table 6). The results indicate that the major constituents of the soil matrix and illuviated clay are mainly Si with lesser Al. Factor analysis of total analysis data (Figures 25, 26 and 27) shows that the soil matrix particularly for Ap horizons has high Na and Ca with some Cl which are associated with relatively high EC values. The mottles and nodules contain high amounts of Fe and some Mn. The chemical composition of illuviated clay as clay coating is quite similar to the composition of associated soil matrix (Figure 28) and the composition of iron oxide mottles and nodules falls on the matrix composition line indicating that they have formed *in situ* (Tawornpruek *et al.*, 2006). A distinct amount of Ti in the soil matrix and mottle of

2Bt horizons of some representative soils (Figures 25b and 26a) represents anatase and indicates that Ti is immobile during pedogenesis (Brimhall *et al.*, 1991a, b; Driese *et al.*, 2000).

Table 5 Micromorphological characteristics of salt affected soils.

Soils	^A Microstructure	Groundmass	Pedofeatures
<i>Pedon1</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged and compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids
<i>Pedon2</i>			
Ang	Moderately to weakly developed SBK and ABK	Open porphyric	Iron oxide typic nodules, impurity crypto-crystalline halite coating
Btng	Moderately to weakly developed SBK and ABK	Open porphyric	Clay coatings and infilling, iron oxide typic nodules
2Btng	Moderately to weakly developed SBK and ABK, single grain	Close porphyric	Clay coatings, iron oxide typic nodules, carbonate materials
<i>Pedon3</i>			
Apng	Moderately to weakly developed ABK	Open to close porphyric	Clay quasi-coating, iron oxide typic nodules, impurity crypto-crystalline halite coating
Btng	Moderately to weakly developed ABK	Open to close porphyric	Clay quasi-coating and infilling, iron oxide typic nodules
<i>Pedon4</i>			
Apng	Compact grain	Sand monic	Impure halite, carbonate materials
Bng	Compact grain	Sand monic	Impure halite, carbonate materials
Btng	Compact grain	Sand monic	Iron oxide impregnative nodules, impure halite coatings
2Btng	Bridged grain	Gefuric	Clay mixed with iron oxide coatings, manganiferrous impregnative nodules, impure halite disseminating in voids
<i>Pedon5</i>			
Apng	Intergrain vesicular	Sand monic	Not present
Btng	Compact grain, bridged grain	Sand monic	Clay coating, manganiferrous impregnative nodules
2Btng	Vughy, crack	Porphyric	Clay mixed with microcrystalline halite mottles, iron oxide impregnative nodules

Table 5 (Continued)

Soils	^AMicrostructure	Groundmass	Pedofeatures
<i>Pedon6</i>			
Apng	Moderately to weakly developed SBK	Porphyric	Iron oxide mottles
ABng	Moderately to weakly developed SBK	Porphyric	Manganiferrous impregnative nodules
Btng	Single grain, bridged grain	Gefuric	Clay coating, iron oxide impregnative nodules
<i>Pedon7</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged grain, compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids
<i>Pedon8</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged grain, compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids, carbonate nodule
2Cng	Compact grain	Close porphyric	Clay mixed with halite and calcite
<i>Pedon9</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged grain, compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids, carbonate nodule
2Ckng	Compact grain	Close porphyric	Clay mixed with halite and calcite
<i>Pedon10</i>			
Apng	Compacct grain, bridged grain	Sand monic	Clay mixed with iron oxides coatings, iron oxide concentric-nucleic nodules
Btcng	Compacct grain, bridged grain	Sand monic	Clay coating, iron oxide concentric-nucleic nodules
Btng	Vughy, fissure	Porphyric	Clay coatings, clay mixed with microcrystalline halite and iron oxide mottles, coatings and infilling
BCng	Crack, vughy	Porphyric	Clay laminated coating, clay mixed with microcrystalline halite infilling
Crng	Laminar rock	Porphyric	Clay coatings
<i>Pedons11-12</i>			
Apng	Channel, moderately to weakly developed SBK	Open porphyric	Crypto-to microcrystalline, iron oxide concentric nodules, halite coatings
Btng	Channel, moderately to weakly developed SBK	Open porphyric	Clay coatings and infilling, iron oxide concentric nodules, halite coatings
2Btng	Channel, moderately to weakly developed SBK	Open porphyric	Clay coatings, manganiferrous and iron oxide impregnative nodules, halite coatings

Table 5 (Continued)

Soils	^AMicrostructure	Groundmass	Pedofeatures
<i>Pedon13</i>			
Apg	Moderately developed SBK	Open porphyric	Iron oxide impregnative nodules
Btg	Channel, moderately to weakly developed SBK	Open porphyric	Clay coating and infilling, iron oxide impregnative and concentric nodules
Btng	Channel, moderately developed SBK	Open porphyric	Clay coatings, iron oxide impregnative and concentric nodules, prismatic gypsum cluster
2Btng	Channel, moderately developed SBK	Open porphyric	Clay coatings, manganiferrous and iron oxide impregnative nodules
<i>Pedon14</i>			
Apg	Channel, vughy	Close porphyric	Iron oxide impregnative and concentric nodules
Btg	Moderately developed SBK	Open porphyric	Clay coatings and infilling, iron oxide impregnative and concentric nodules
2Btg	Moderately developed SBK	Open porphyric	Manganiferrous and iron oxide impregnative nodules, halite coatings
<i>Pedon15</i>			
Apg	Granular, SBK	Open porphyric	Iron oxide impregnative nodules
Btg	SBK, channel	Open porphyric	Clay coatings and infilling, iron oxide impregnative and typic nodules
2Btng	Moderately to weakly developed SBK	Open porphyric	Clay coatings, iron oxide impregnative and concentric nodules
<i>Pedon16</i>			
Apng	Intergrain microaggregate	Porphyric	Sharp and diffuse calcite nodules, carbonate materials
Btg	Intergrain microaggregate	Porphyric	Clay coatings, manganiferrous impregnative nodules
BCKg	Intergrain microaggregate	Porphyric	Clay mixed with calcite, calcite nodules
<i>Pedon17</i>			
Apng	Compact grain	Sand monic	Iron oxide mottles, halite
Bng	Compact grain	Sand monic	Manganese oxide mottles, halite
Btng	Compact grain, bridged grain	Open to close porphyric	Clay coating iron oxide nucleic-concentric nodules, halite coatings
2Btng	Compact grain, bridged grain	Close porphyric	Clay and clay mixed with iron oxide coatings, halite coating
<i>Pedon18</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged grain, compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids

Table 5 (Continued)

Soils	^AMicrostructure	Groundmass	Pedofeatures
<i>Pedon19</i>			
Apng	Single grain	Open porphyric	Manganiferrous impregnative nodules, halite coating on the wall of voids
Btng	Bridged grain, compact grain	Close porphyric	Clay coatings, halite coating on the wall of voids
Cng	Compact grain	Close porphyric	Not present
<i>Pedon20</i>			
Apg	Vughy	Sand monic grading to chitonic	Ferruginous impregnative nodules
Bcg	Fissure	Open porphyric	Clay mixed with iron oxide coatings, concentric ferruginous nodules
Btg	Crack	Open porphyric	Clay mixed with iron oxide mottles
2Btng	Vughy	Close porphyric	Clay mixed with iron oxide coatings and infilling, iron oxide impregnative s-matrix
<i>Pedon21</i>			
Apg	Compact grain	Sand monic grading to chitonic	Iron oxide concentric-nucleic nodules
Bcg	Compact grain	Close porphyric	Iron oxide concentric nodules, manganiferrous impregnative nodules
Btg	Compact grain	Open to close porphyric	Clay mixed with iron oxide coatings, iron oxide impregnative s-matrix
2Btg	Vughy	Close porphyric	Clay mixed with iron oxide coatings and infilling, iron oxide impregnative s-matrix
2Btng	Vughy	Close porphyric	Clay mixed with iron oxide coatings

^A ABK= angular blocky, SBK = subangular blocky

Table 6 Total analysis using a microprobe of some pedological features in the genetic horizons of representative salt affected soils.

Pedon	Genetic horizon	Pedological feature	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃
-----%-----													
P3	<i>Vertic Natraqualf, fine-loamy, mixed, semiactive, isohyperthermic</i>												
	Ang	Matrix	1.25	1.75	24.41	58.99	0.01	1.80	2.17	2.02	0.86	0.04	7.31
		Mottle, Nodule	nd										
	Btng	Matrix	1.09	1.01	22.24	67.51	0.00	0.37	0.99	0.98	1.06	0.01	5.04
		Illuviated clay	0.72	1.14	27.68	58.55	0.00	0.03	1.35	0.64	0.80	0.00	9.02
		Mottle	0.76	0.74	18.22	34.26	0.00	0.40	0.73	0.69	1.08	0.11	42.95
		Nodule	nd										
	Btng	Matrix	1.04	1.44	25.74	61.69	0.02	0.97	2.00	1.34	0.79	0.00	5.27
		Illuviated clay	nd										
		Mottle	0.68	0.75	12.56	26.31	0.00	0.63	0.89	0.92	0.34	0.00	56.73
		Nodule	nd										
P4	<i>Typic Natraqualf; coarse-loamy, mixed, ishyperthermic</i>												
	Apng	Matrix	8.92	6.99	12.08	54.91	0.28	2.42	2.29	5.72	0.66	0.13	5.59
		Mottle, Nodule	nd										
	Btng	Matrix	1.17	1.07	28.57	60.04	0.00	0.00	1.59	0.67	0.93	0.00	5.95
		Illuviated clay	1.45	1.21	31.93	56.86	0.00	0.00	1.91	0.46	0.87	0.00	5.32
		Mottle	0.89	1.61	19.34	47.12	0.00	0.00	0.98	1.65	0.36	0.25	27.79
		Nodule	nd										
	2Btng	Matrix	0.78	1.45	17.81	68.63	0.00	0.07	0.92	0.29	4.08	0.00	5.98
		Nodule gray	1.10	1.29	22.09	58.40	0.00	0.08	1.41	0.50	0.54	0.09	14.47
		Nodule white	0.63	0.55	10.17	7.47	0.00	0.29	0.04	0.06	0.14	0.00	80.65
		Illuviated clay	1.22	1.37	26.68	58.79	0.00	0.02	1.88	0.28	0.50	0.00	9.24
		Mottle	1.48	1.27	22.66	51.91	0.00	0.02	1.45	0.41	4.92	0.00	15.88
P11	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>												
	Apng	Matrix	0.73	1.07	29.78	55.95	0.00	0.36	1.53	0.99	1.13	0.00	8.46
		Mottle	1.00	0.53	14.96	22.26	0.16	0.55	0.51	0.80	0.54	0.42	58.27
		Nodule	0.58	0.22	9.58	9.51	0.00	0.40	0.17	0.10	0.26	0.32	78.85
	Btng	Matrix	0.63	0.76	33.64	55.15	0.00	0.07	0.97	0.71	1.57	0.00	6.51
		Illuviated clay	0.58	1.03	34.31	53.78	0.00	0.03	1.42	0.81	0.74	0.05	7.24
		Mottle	0.65	0.84	27.95	40.65	0.00	0.14	0.88	0.83	0.65	0.06	27.36
		Nodule	nd										

Table 6 (Continued)

Pedon	Genetic horizon	Pedological feature	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃
-----%													
P17	2Btng	Matrix	1.10	1.20	23.51	64.07	0.00	0.13	1.28	1.59	0.68	0.00	6.42
		Illuviated clay	0.77	1.00	31.39	55.74	0.00	0.05	1.24	1.00	1.40	0.00	7.40
		Mottle	0.86	0.53	9.96	16.32	0.02	0.75	0.31	0.73	2.71	29.55	38.15
		Nodule	nd										
	<i>Typic Natraqualf; sandy, silicious, isohyperthermic</i>												
	Apng	Matrix	4.44	1.70	9.58	72.90	0.19	2.28	0.76	3.53	0.78	0.14	3.70
		Mottle, Nodule	nd										
	Btng	Matrix	1.22	1.81	27.80	59.98	0.00	0.01	1.53	0.54	0.95	0.00	6.16
		Illuviated clay	1.01	1.58	26.79	59.63	0.00	0.00	1.43	0.42	0.99	0.11	8.02
		Mottle	0.88	0.98	10.82	28.26	0.00	0.13	0.80	0.51	0.25	3.48	53.88
		Nodule	0.42	0.52	5.49	5.94	0.28	0.21	0.04	0.18	0.02	0.48	86.38
	2Btng	Matrix	0.93	1.56	26.56	59.15	0.00	0.01	1.79	0.37	0.73	0.00	8.90
		Illuviated clay	1.03	1.49	25.65	62.10	0.00	0.00	2.00	0.37	0.77	0.00	6.58
		Mottle	0.76	0.83	12.89	17.15	0.00	0.10	0.41	0.27	0.52	0.00	67.07
		Nodule	0.38	0.47	5.15	7.99	0.21	0.20	0.08	0.09	0.04	0.00	85.39
P21	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>												
	Apg	Matrix	1.11	1.50	10.61	80.25	0.49	0.04	0.34	2.84	1.11	0.00	1.72
		Mottle, Nodule	nd										
	Btg	Matrix	0.29	0.54	35.33	56.22	0.00	0.01	0.61	0.65	1.95	0.00	4.40
		Illuviated clay	0.22	0.58	35.12	51.67	0.00	0.00	0.56	0.54	0.92	0.00	10.40
		Mottle	0.42	0.46	15.10	17.24	0.00	0.00	0.20	0.22	0.54	0.13	65.69
		Nodule	nd										
	2Btng	Matrix	0.48	0.53	33.63	58.18	0.01	0.01	0.49	0.81	2.15	0.00	3.71
		Illuviated clay	0.20	0.54	37.54	54.33	0.00	0.01	0.62	0.68	0.97	0.00	5.12
		Mottle, Nodule	nd										

nd= not detected

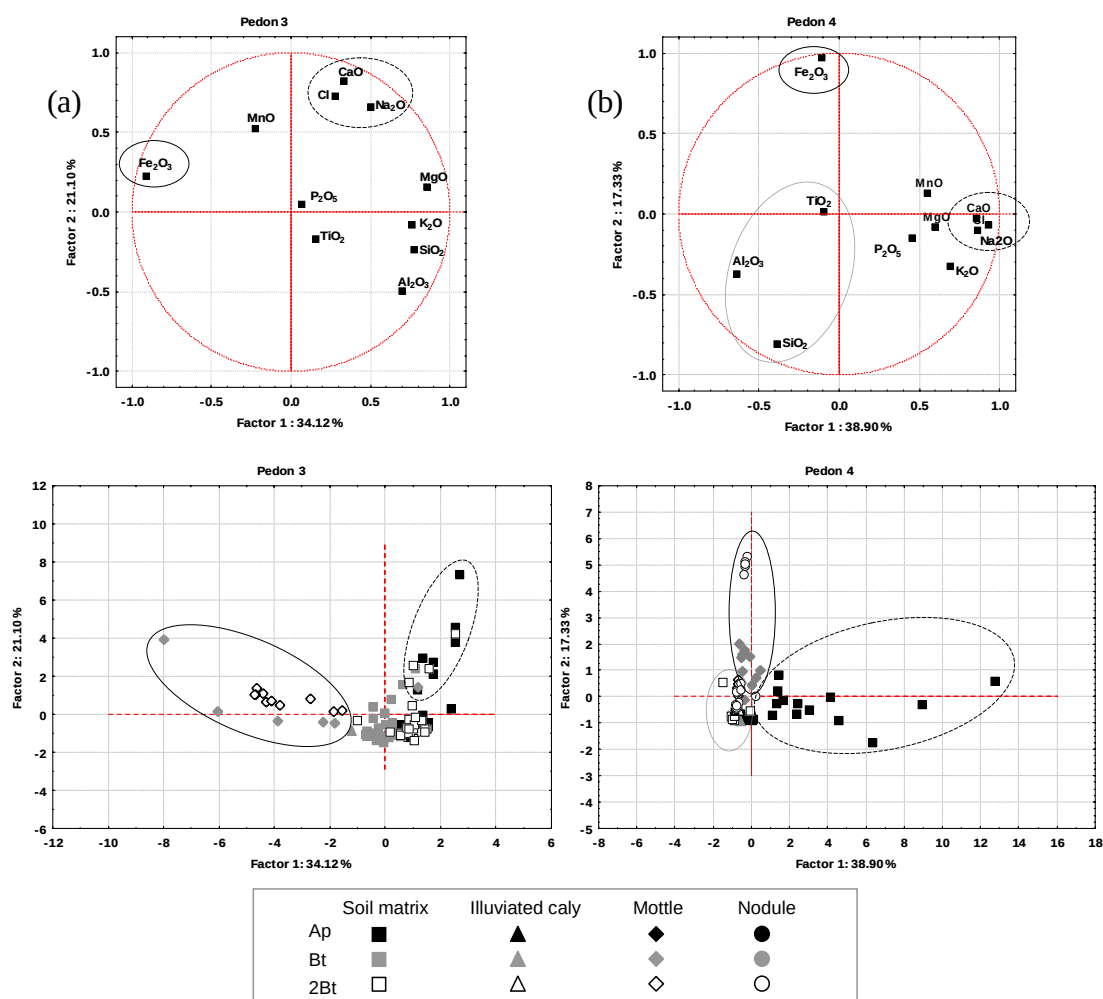


Figure 25 Factor analysis for total analyses using an X-ray microprobe of pedological features: soil matrix, illuviated clay, mottle and nodule in the Ap, Bt and 2Bt horizons of Pedon 3 (a) and Pedon 4 (b).

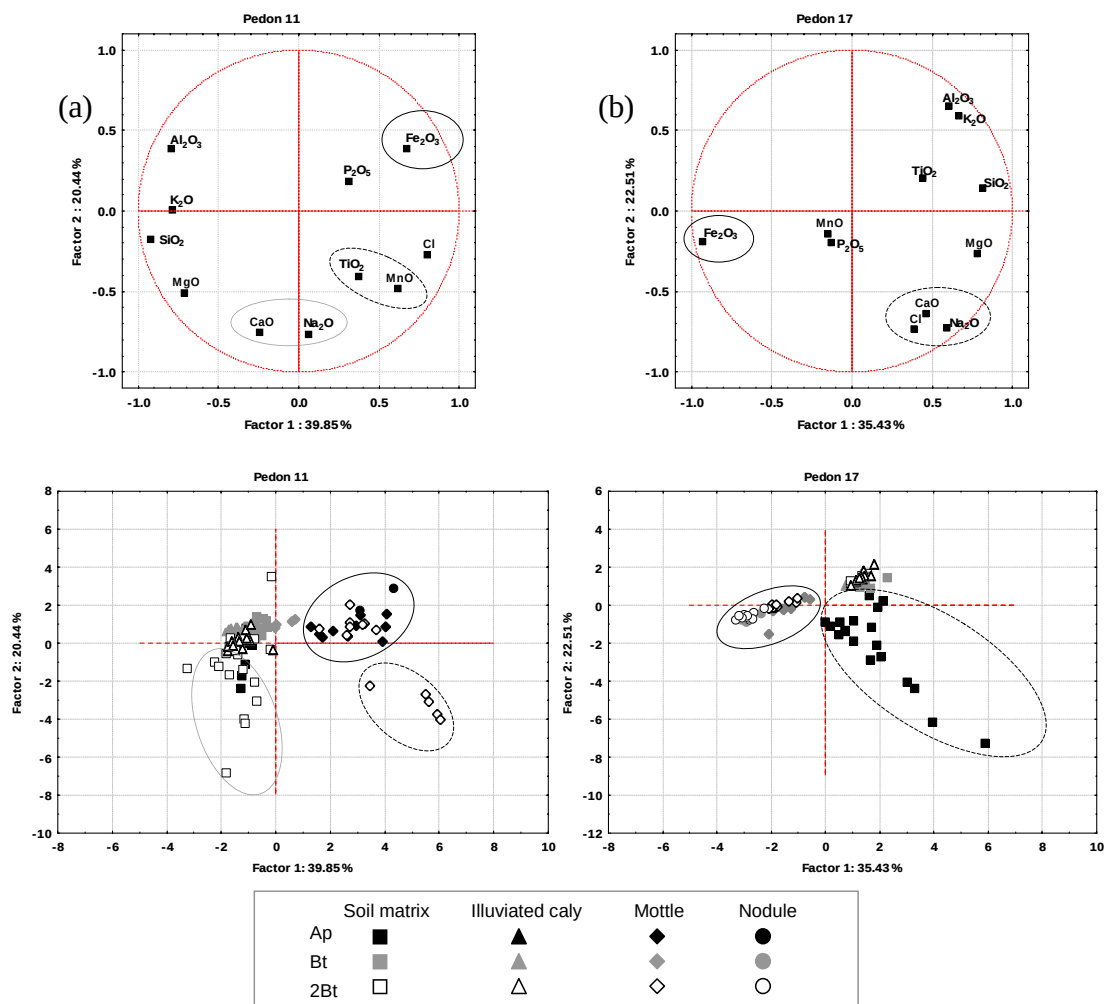


Figure 26 Factor analysis for total analyses using an X-ray microprobe of pedological features: soil matrix, illuviated clay, mottle and nodule in the Ap, Bt and 2Bt horizons of Pedons 11 (a) and 17 (b).

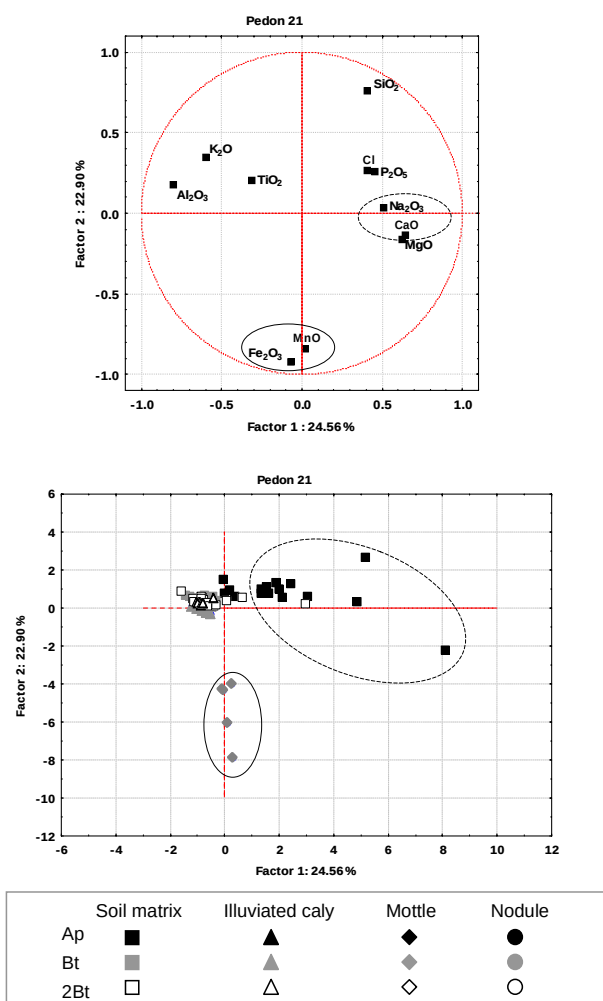


Figure 27 Factor analysis for total analyses using an X-ray microprobe of pedological features: soil matrix, illuviated clay, mottle and nodule in the Ap, Bt and 2Bt horizons of Pedon 21.

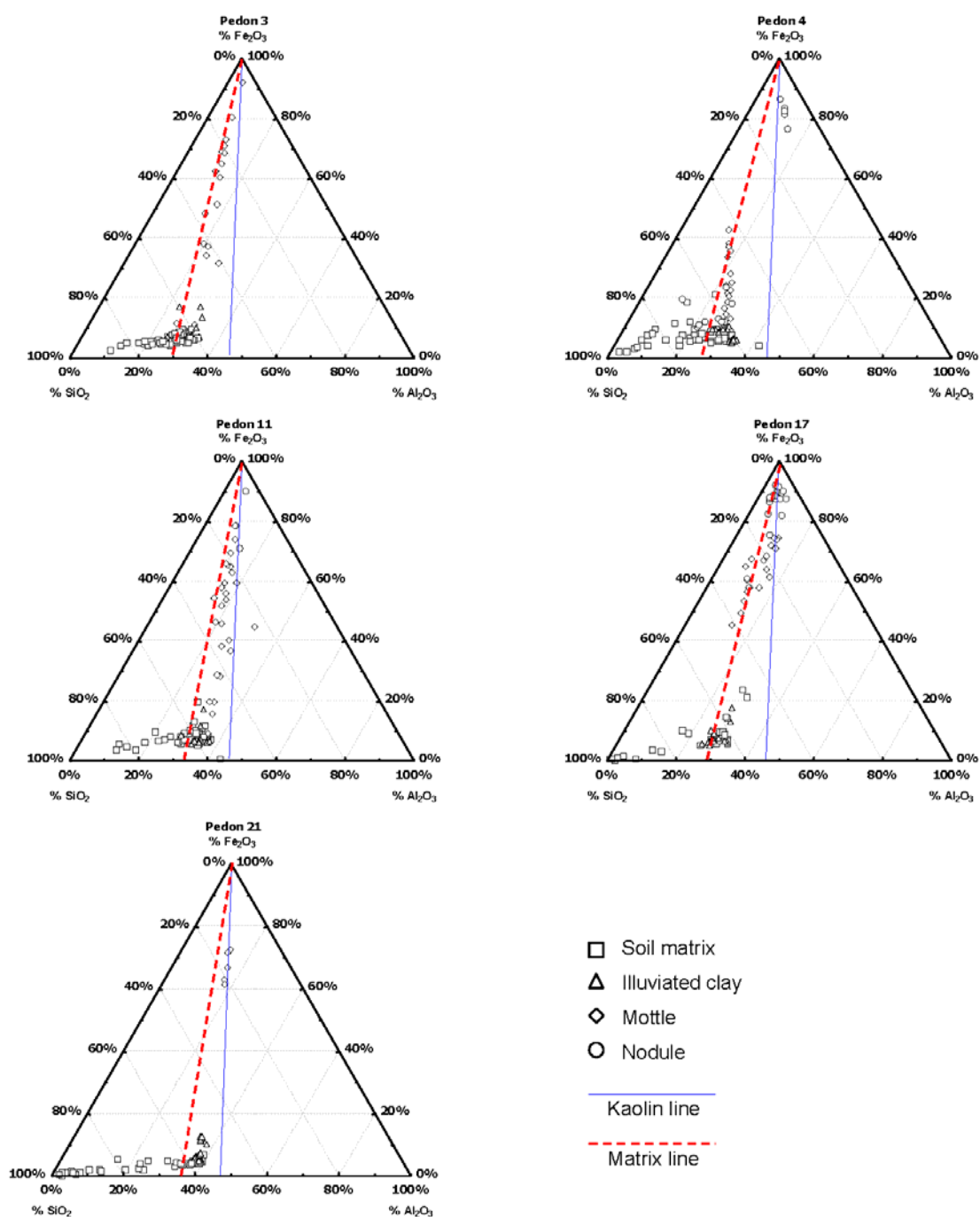


Figure 28 Normalized composition triangular graphs for Ap, Bt and 2Bt horizons of representative salt affected soils.

Pedogenesis and Classification of Salt Affected Soils

Results for soil characteristics reveal that these are moderately to highly developed soils since they have medium to low exchangeable bases (Ca, Mg and K). The loss of these cations indicates that they have undergone long-term weathering and leaching under a tropical savanna climate with the wetter climate in the past inducing argillic and kandic horizons by illuviation and lessivage.

Accumulation of soluble salts in the soils and the presence of carbonate materials in some soils reflect a change in soil environment as drier climate and limited leaching producing a natric horizon. Exchangeable sodium is a prominent ion contributing to a base saturation percentage greater than 35%. Most soils are saline-sodic which is attributed to salinization and alkalization being the dominant pedogenic processes. Some soils (Pedons 14 and 16) show that they are in the first stage of salt affected soil formation in which salinization is a dominant process, whereas Pedons 20 and 21 do not show evidence of salts indicating the dominance of desalinization and alkalization. Therefore, all soils have been affected by salts in a later stage of soil development, except for Pedon 10 that has directly developed from salt-rich parent rock.

Based on USDA Soil Taxonomy (Soil Survey Staff, 2006), all soils are Alfisols and their suborder is Aqualf because they show evidence of clay illuviation in B horizon of more than 1% with having base saturation percentage of more than 35% and developed under aquic condition as previously mentioned. All soils, excluding Pedons 14 and 16, have sodium accumulations in the B horizon as a natric horizon and can be classed as Natraqualfs. Pedon 14 does not have a natric horizon or other salt affected properties in the subsoil and is an Endoaqualf. Pedon 16 does not have a natric horizon with low CEC clay ($\leq 16 \text{ cmol}(+) \text{ kg}^{-1}$) and ECEC clay ($\leq 12 \text{ cmol}(+) \text{ kg}^{-1}$) in the subsoil, so it is a Kandiaqualf.

All Natraqualfs are Typic Natraqualfs except for Pedons 2 and 3 that belong to the Vertic subgroup due to the presence of cracks within 125 cm of the soil surface that are 5 mm or wider and slickensides in a layer thicker than 15 cm. Kandiaqualf has a hue

of 10YR and both a color value of more than 3 and chroma of more than 3 in the upper part of the soil profile, thus it can be classed as Aeris Kandiaqualf. The taxonomic names of soils including the family name are shown in Table 7.

Table 7 Classification of salt affected soils following Soil Taxonomy (Soil Survey Staff, 2006).

Profile	Classification	Salt affected soil group
Pedon 1	Coarse-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 2	Fine-loamy, mixed, isohyperthermic Vertic Natraqualf	Saline-sodic
Pedon 3	Fine-loamy, mixed, semiactive, isohyperthermic Vertic Natraqualf	Saline-sodic
Pedon 4	Coarse-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 5	Fine-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 6	Fine, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 7	Fine-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 8	Fine-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 9	Fine, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 10	Loamy-skeletal, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 11	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 12	Very fine, kaolinitic, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 13	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 14	Fine, kaolinitic, isohyperthermic Typic Endoaqualf	Saline
Pedon 15	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 16	Fine-loamy, mixed, isohyperthermic Aeris Kandiaqualf	Saline
Pedon 17	Sandy, silicious, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 18	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 19	Coarse-loamy, mixed, isohyperthermic Typic Natraqualf	Saline-sodic
Pedon 20	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Sodic
Pedon 21	Fine, kaolinitic, isohyperthermic Typic Natraqualf	Sodic

Aggregate Stability of Salt Affected Kaolinitic Soils

Aggregate stability is influenced by clay content and soil mineralogy and closely related to sodicity for clayey soils (Frenkel *et al.*, 1978; Levy and Mamedov, 2002). Generally kaolinitic soils have the greatest aggregate stability (Wakindiki and Ben-Hur, 2002). Kaolinitic soils which predominate in this region of Thailand were studied to establish the relationships between aggregate stability and soil properties.

Soil Aggregate Stability

The aggregate stability percentage for these soils ranges from 3-91 % (Figure 29) with subsoil aggregates mostly being more stable than topsoil aggregates. More stable aggregates in the subsoils are due to clay acting as a cementing material as is commonly the case when the soil contains > 20% clay (Ben-Hur *et al.*, 1985).

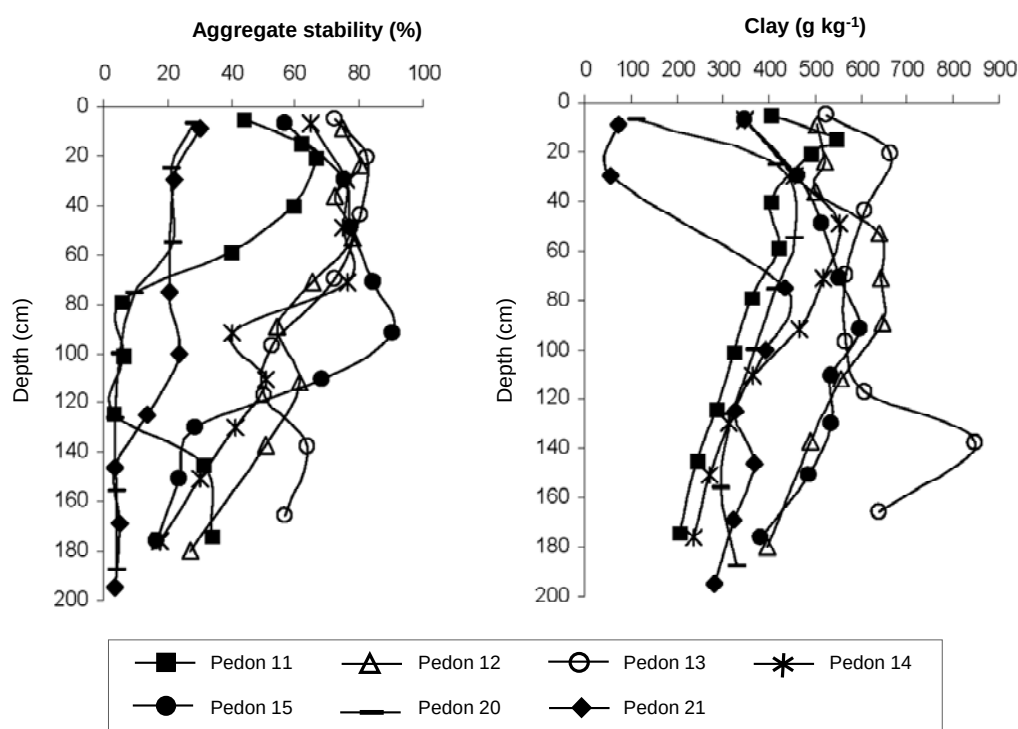


Figure 29 Aggregate stability percentages and clay content for the seven soils plotted against depth.

The lower aggregate stability in some horizons may be due to the presence of minor amounts of smectite and illite (Wakindiki and Ben-Hur 2002). The relatively low stability of topsoil aggregates may be due to the soil being regularly disturbed by plowing and puddling during rice cultivation.

The Relationship between Aggregate Stability and Soil Properties

Based on the bivariate relationships between aggregate stability and some soil properties (Figure 30, Appendix Table 3) the soil property that is most strongly correlated with aggregate stability is pH ($r = -0.84$) followed by exchangeable K ($r = +0.75$), CEC by sum ($r = +0.73$), clay content ($r = +0.72$), extractable acidity ($r = +0.66$) and organic matter ($r = +0.66$). Aggregate stability is not significantly related to ESP, SAR, and EC for these soils. This result contrasts with the findings of many studies that have reported highly significant negative relationships between both ESP and SAR and aggregate stability (e.g. Rengasamy and Olsson, 1991; Levy *et al.*, 1993; Garcia-Orenes *et al.*, 2005; Levy, 2000).

However some studies that have included a wide range of soil textures as is the case with these Thai soils have also observed that there was no relationship between aggregate stability and ESP (Coughlan and Loch, 1984; Goldberg *et al.*, 1988). For example, aggregate stability in fine kaolinitic, Typic Haploxerults was not significantly affected by increasing SAR (Ruiz-Vera and Wu, 2006) and there was no relationship between the EC and aggregate stability for tropical Ultisols from Malaysian Borneo (Chappel *et al.*, 1999). The published data for tropical soils are thus consistent with the present results. These results are also consistent with the known influence of clay mineralogy on soil dispersivity (Oades and Waters, 1991; Levy *et al.*, 1993). The structural stability of kaolin-dominated soils is high which is attributed to the high binding capacity of the mineral. Kaolinite is usually in a flocculated state because at normal soil pH values the attraction of the positively charged edges to the negatively charged planar surfaces of crystals gives rise to an edge-to-face flocculation mode. However Ruiz-Vera and Wu (2006) stated that because kaolin has a much lower charge density than smectite bonds are weak in kaolinitic soil aggregates.

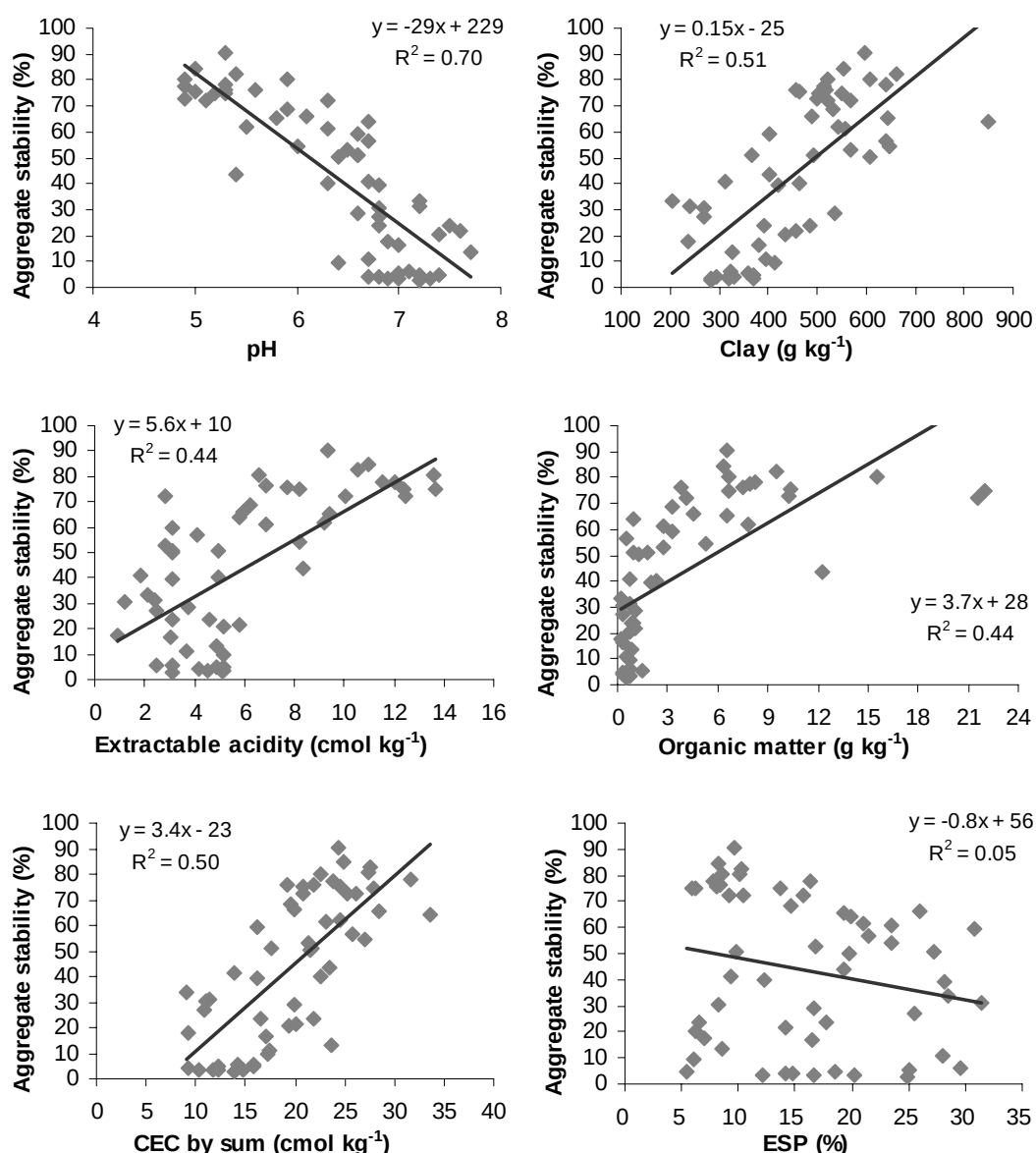


Figure 30 Relationships of aggregate stability with some properties of the soils.

For these Thai soils, aggregate stability shows a strong negative relationship with soil pH as has also been reported by some other workers (Suarez *et al.*, 1984; Keren *et al.*, 1988; Chorom *et al.*, 1994; Lieffering and McLay, 1996) who suggested that with increasing soil pH clay dispersion occurs as a result of increased repulsion of negatively charged clay particles. Additionally, Levy and Miller (1997) found that salinity does not affect dispersion where soil pH is less than 6.5.

Aggregate stability increases with increasing clay content for these Thai soils and many other studies have also demonstrated a positive relationship between clay content and aggregate stability so that clay may be considered to be a dominant cementing agent (Gollany *et al.*, 1991; Shainberg *et al.*, 1992; Curtin *et al.*, 1994; Levy *et al.*, 2003). However, the cementing effect of clay depends *inter alia* on its mineralogy. At high SAR values and low electrolyte concentrations, soils with high contents of kaolinite and sesquioxides are relatively stable (McNeal *et al.*, 1966) with little swelling and dispersion (Ruiz-Vera and Wu, 2006). Aggregate stability generally increases with increasing organic matter but for the Thai soils the relationship is weak ($R^2 = 0.44$) and is not systematic (Figure 30) possibly because organic matter does not greatly influence aggregate stability when the organic matter content of the soil is low (Nwadialo and Mbagwu, 1991).

Multivariate stepwise regression analysis of original and transformed data has been investigated to develop an equation to predict aggregate stability incorporating several soil properties. A combination of only two soil properties is highly predictive of aggregate stability.

$$\% \text{Aggregate stability} = 149 - 22\text{pH (H}_2\text{O)} + 0.078\text{Clay (g kg}^{-1}\text{)} \quad R^2 = 0.80$$

Inclusion of extractable acidity, CEC, exchangeable K and organic matter in multivariate equations and consideration of minor clay mineral associations did not significantly improve the prediction of aggregate stability. Aggregate stability estimated from this equation is compared with the measured aggregate stability (Figure 31). The result shows a close and systematic relationship between predicted and measured aggregate stability with few significantly outlying data points.

The stability of soil aggregates in these salt affected soils under a tropical savanna climate is apparently most strongly influenced by the effect of soil pH on clay surface reactions. As the soil pH decreases below 6, the soil solution contains elevated concentration of Fe and Al complexes which are adsorbed and may tend to flocculate clay (Rengasamy and Olsson, 1991). In addition, in predominantly kaolinitic soils, pH affects

surface charge due to the variable charge nature of clay crystal edges. Increasing pH leads to a charge reversal on the edges of the kaolinitic clay particles, from positive to negative (Schofield and Samson, 1954; Tombacz and Szekeres, 2006). This, in turn, weakens the bonds between positive and negatively charged surface sites on adjacent particles and thus has an adverse effect on the stability of the aggregates (Chang *et al.*, 1987).

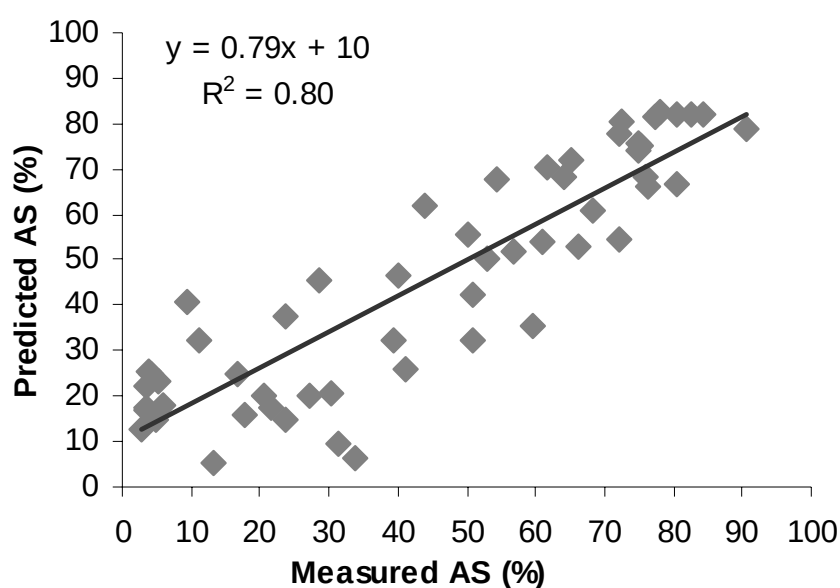


Figure 31 Aggregate stability (AS) percentage predicted by the multivariate relationship versus measured values for the soils.

Distribution Trends of Salt Affected Soils

Salt affected soils mostly occur in the Northeast Plateau basins and are extensive in the Khorat Basin under the various environmental conditions with variations in salinity between each location. In this study, the relationship between environmental conditions and the distribution of these salt affected soils was investigated in detail.

Soil Salinity Distribution in Relation to Environmental Conditions

Variation of soil salinity with depth is shown in Figure 32. Based on electrical conductivity (EC) and bulk density of soils, the amounts of salts in the soil profiles (depth of 2 m) calculated range from 241 to 3115 ton ha⁻¹ (Figure 33). Salt content in these soils relates to the average rainfall but the relationship is generally low ($R^2 = 0.46$) and is not systematic (Figure 34) indicating some additional factors influence on salt accumulation for these soils.

Environmental conditions of these soils consisting of rainfall (RF, mm y⁻¹), landform (LF), rock type (RT), parent material (PM), surface slope (S), land use (LU) and soil texture (ST) were used as the factors to develop an equation to predict the relationship between environmental conditions and salt accumulation for these soils using multivariate stepwise regression analysis. A combination of five factors, RF, LU, RT, PM and S, is highly predictive of the salt content in the soil profiles. The full steps of the multivariate stepwise regression analysis are given in Appendix Table 4 and 5.

$$\text{Log [Salt content]} = 14.39 - 3.77 \log [\text{RF}] - 0.17[\text{LU}] - 0.19[\text{RT}] + 0.14[\text{PM}] + 0.15[\text{S}]$$

$$R^2 = 0.73$$

The salt content (ton ha⁻¹) estimated from this equation is compared with the measured salt content (Figure 35). The result shows a close and systematic relationship between predicted and measured salt content with a few significantly outlying data points. Thus, salinity distribution for these soils is the result of the basin microenvironment including rainfall, soil parent material, rock type, land use and surface slope. Regarding

the relationship between salt content and rainfall, three groups of soils with different behaviours are recognized (Figure 34).

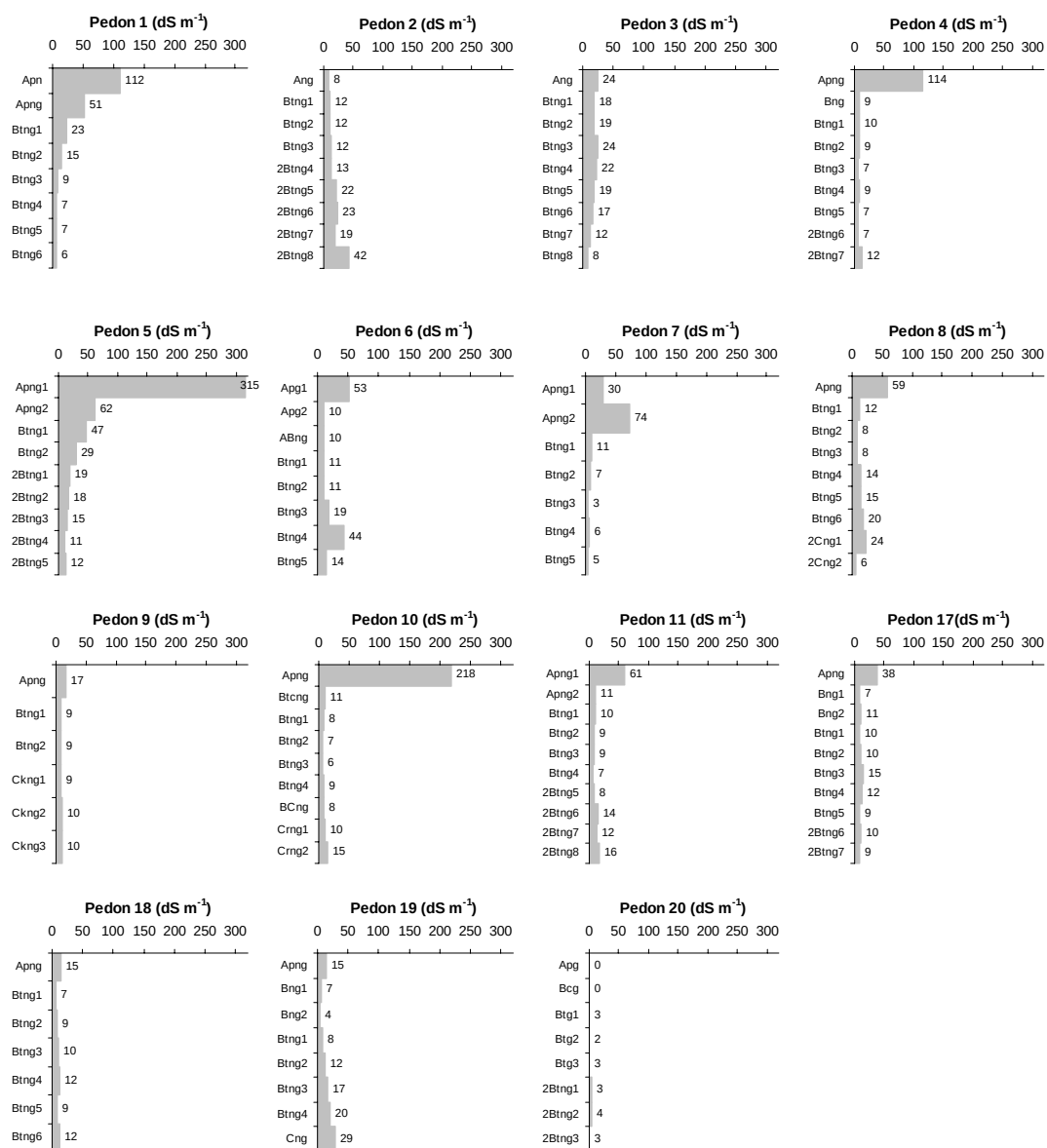


Figure 32 Variation of electrical conductivity (dS m⁻¹) with depth for the soils.

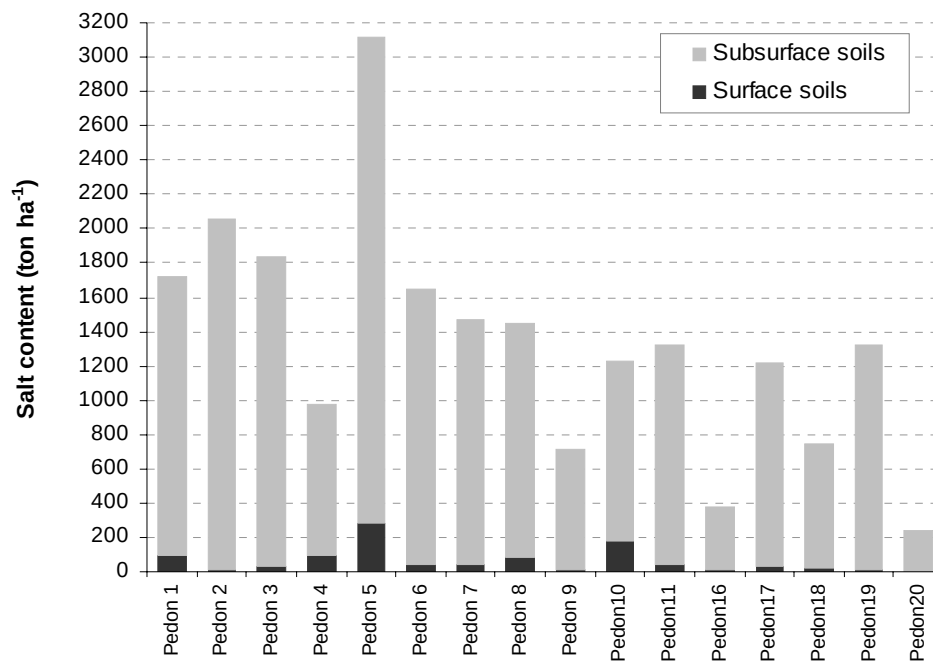


Figure 33 Salt content of the soil profiles at each location.

Group 1 comprises Pedons 1-8, 10-11, 17 and 19 that have high salt content in their profiles under a relatively low rainfall ($907\text{--}1,040\text{ mm y}^{-1}$) and these mostly occur in the western edge of the basin. There are variations of salt content within the same range of rainfall (Figure 34). These variations are related to the presence of a residual layer derived from the weathered salt bearing rocks. Salt tends to accumulate where the shallow residual layer is present as Pedons 2 and 5 clearly show high salt content in their profiles under the lower rainfall and with a shallower residual layer. Therefore, their salinity is controlled by the residual layer, surface slope and interflow water is an important salt distributing agent.

Group 2 consists of Pedons 18 and 20 that are under higher rainfall. They are located in the lowest position of the landscape with a presence the residual layer in some profiles, but the salt content in their profiles is low. This indicates the rainfall as a major controlling factor of soil salinity. Pedon 20 clearly shows by its low EC and low ESP under the annual rainfall of $1,237\text{ mm}$ that the soil is undergoing salt leaching (desalinization).

Group 3 includes Pedons 9 and 16 that have lower salt content comparing with that of Group 1 and occur in the low rainfall areas. Both soils show calcareous accumulations in the lower part of profiles indicating that local climatic conditions with low rainfall do not allow leaching of carbonates from soils (Dultz and Kuhn, 2005). Pedon 16 is a saline soil with salt accumulation (EC value ≥ 4 dS m⁻¹) only in the upper part of the profile and no occurrence of salt accumulation in the lower layer in the profile. This implies that the soil is in the first stage of salt affected soil formation due to unbalanced hydrology of soils (Buol *et al.*, 2003; Schaetzl and Anderson, 2005) as subsurface water flow is limited. This can be a result of the adjacent infrastructure as a road which lies in the SW-NE direction blocks the flow of subsurface water.

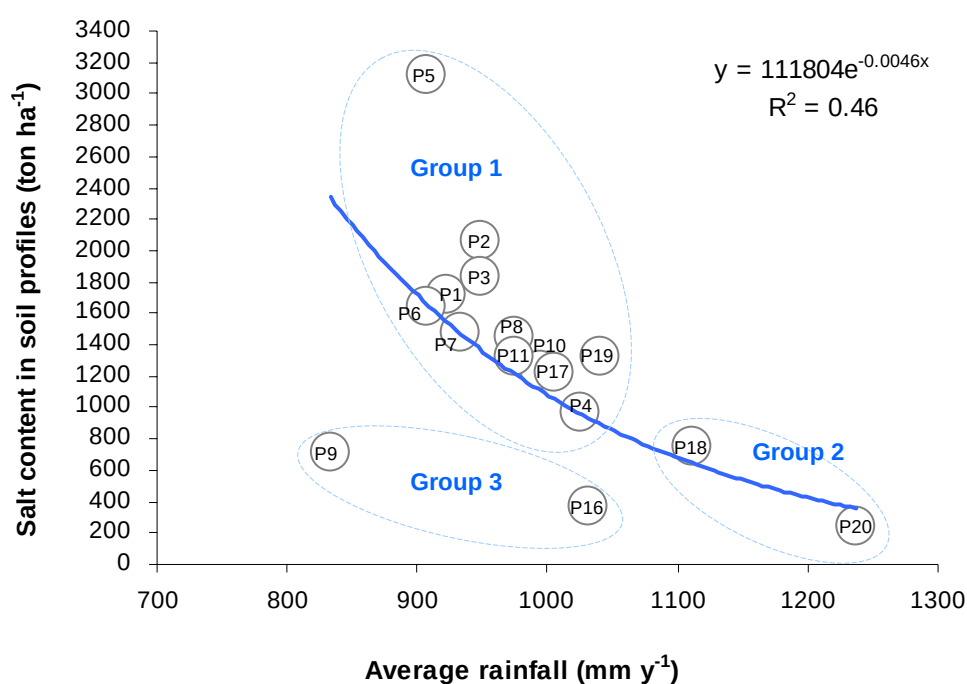


Figure 34 Relationship between salt content and average rainfall.

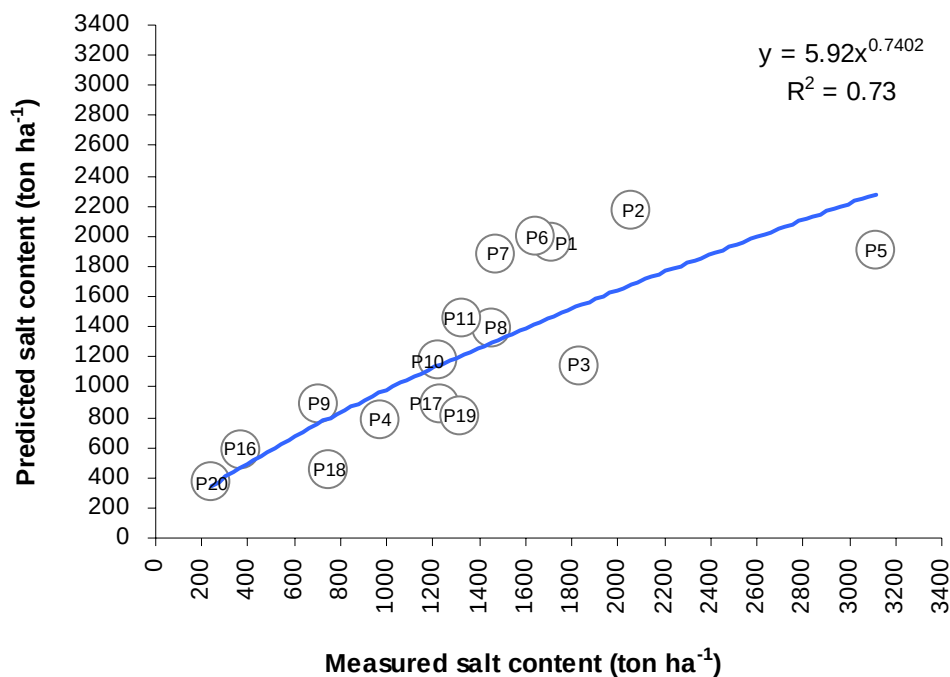


Figure 35 Salt content in the soil profiles predicted by the multivariate relationship versus measured values for the soils.

Spatial Distribution of Salt Affected Areas and Their Macroenvironments

GIS analysis results show that salt affected areas occur throughout the basin (Figure 36a). They are distributed in the lowland of this region and are commonly bordered by higher areas underlain by salt bearing bedrocks, particularly in the west. Highly to moderately salt affected areas are present as small areas and are mostly located in the west. Whereas, slightly salt affected areas are distributed widely in some parts of each province.

The extent of salinity shows a decreasing trend from the western part towards the eastern part of the basin. Based on geology of the basin, most salt affected areas occur on the Maha Sarakham Formation (Figure 36b), contributing approximately 76 percent of the total salt affected area. Other areas are on Quaternary fluvial deposits and are mostly slightly salt affected. Moreover, these salt affected areas distribute as a continuously line

along the Khok Kruat Formation fold in the western fringe of the basin and also along the Quaternary terrace deposits in the southern part of the basin.

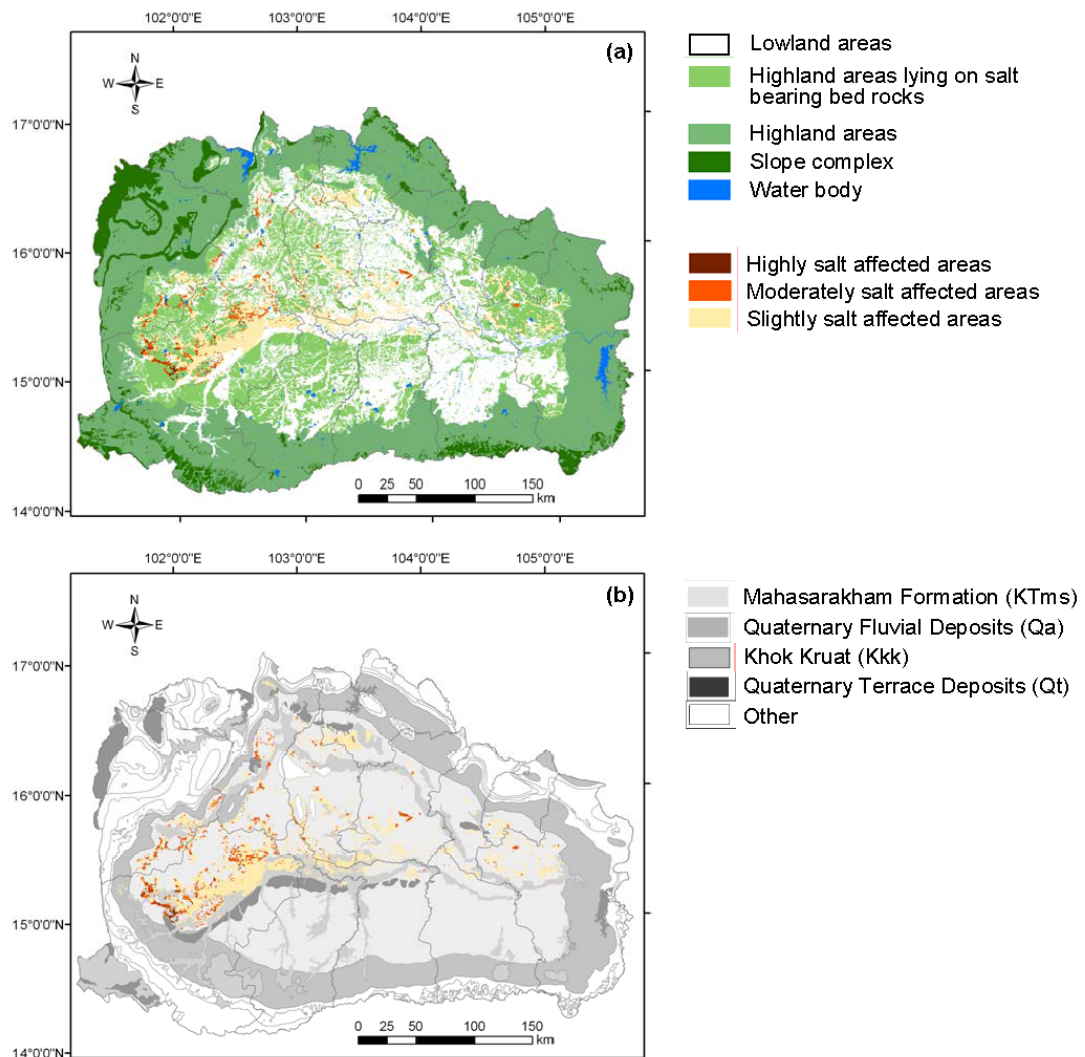


Figure 36 Distribution of salt affected areas with physiography (a) and geology (b) of the Khorat Basin.

Considering the rainfall distribution with respect to salt affected areas (Figure 37), there are three of rainfall ranges. Highly salt affected areas with high salt content in the profile receive rainfall less than 1100 mm y^{-1} , slightly salt affected areas with a low salt content in the profile receive rainfall ranging from $1100\text{-}1600 \text{ mm y}^{-1}$ and non-salt

affected areas receive more than 1600 mm y^{-1} . Therefore, all salt affected areas in this basin occur under a rainfall less than 1600 mm y^{-1} .

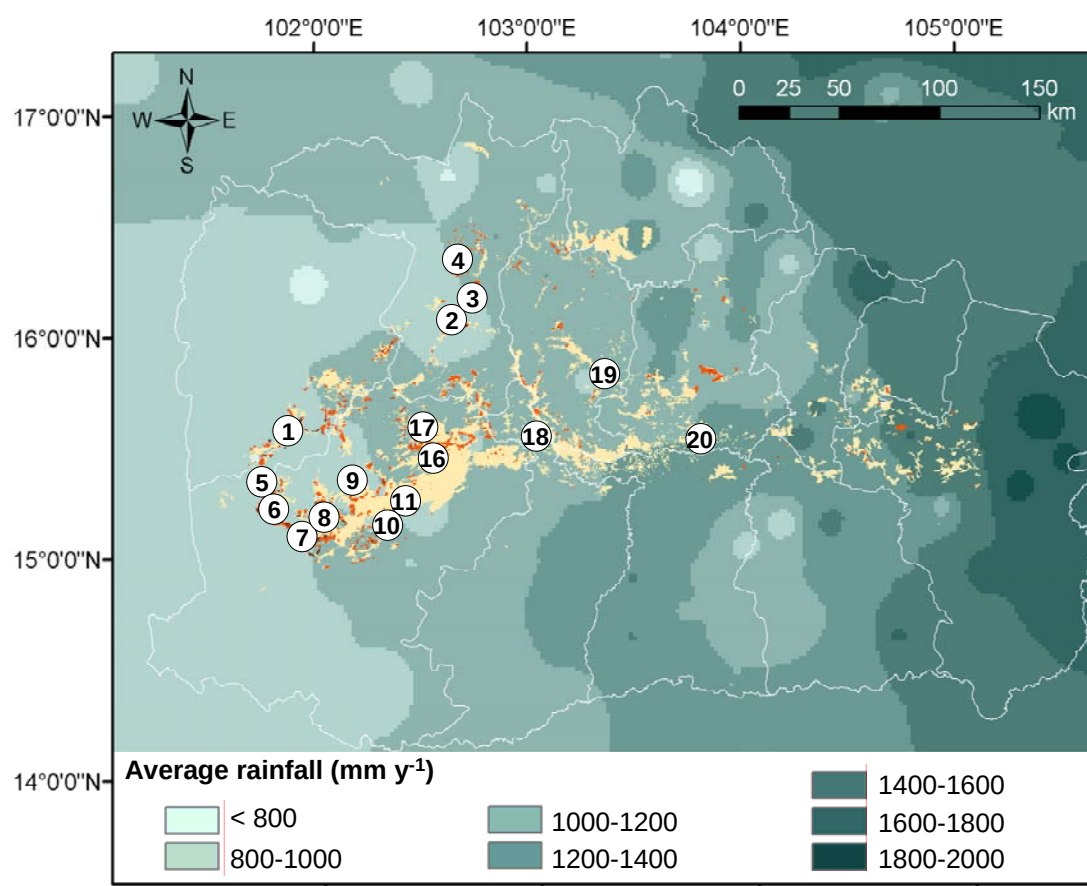


Figure 37 Salt affected soil distribution and average rainfall in the Khorat Basin.

Distribution Trends of Salt Affected Soils in the Khorat Basin

Data on environmental conditions, spatial distribution of salt affected areas and the distributions of salt content illustrate that salt affected soils show trends of distribution in three directions (Figure 38). On the western (W) rim of the basin, distribution of soils (Pedons 1-8, 10 and 11) relates to the Khok Kroat Formation and salt content in the profiles is mostly high. In the west to northeast (W-NE) direction, the distribution of soils (Pedons 9, 16-17 and 19) relates to the physiography of the basin as it tilts toward the northeast. Pedon 9 is on the highest position followed by Pedons 16-17 and 19. Salt

content in the profiles is mostly lower than for the first direction. In the west to east (W-E) direction, soils (Pedons 18 and 20) are in the lowest position of the basin with a low salt content in their profile especially Pedon 20. Distribution of these soils reflects the higher rainfall.

As the basin is rimmed by an escarpment in the western, northern and southern edge, the distribution of salt affected soils tends to be widespread in the west of the basin where evaporation is high and reflecting the presence of a shallow residual layer towards the northeast of the basin, salinity tends to decrease in the east of the basin where the rainfall increases. Additionally, the distribution of these soils along the southwest direction is clearly blocked by the Quaternary Terrace Deposits.

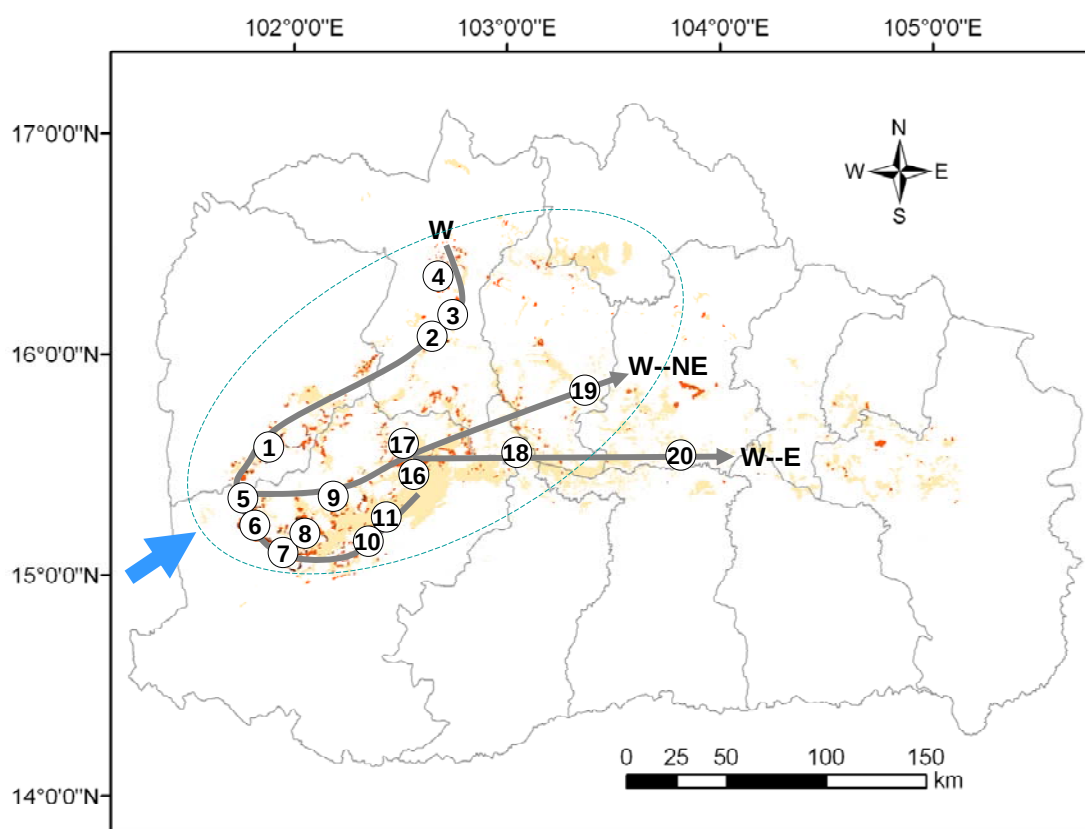


Figure 38 Distribution trend of salt affected soils in the Khorat basin.

CONCLUSIONS

Results of this study on distribution trends of salt affected soils in Northeast Plateau Basins of Thailand reveal that they are moderately to highly developed soils. They have undergone long-term weathering and leaching under a wetter tropical climate in the past and have been affected by salts in the later stage of soils development when the soil environments changed in a drier climate. However, Pedon 10 has directly developed from salt-rich parent rock that is residuum derived from sedimentary rock. This residual layer is the main source of salts in these soils. Most soils are saline-sodic as Typic Natraqualfs and Vertic Natraqualfs for Pedons 2 and 3. Saline soils occur as Typic Endoaqualf for Pedon 14 and Aeric Kandiaqualf for Pedon 16. Sodic soils are also present as Typic Natraqualfs for Pedons 20 and 21.

Sodicity is not affecting aggregate stability for these salt affected kaolinitic soils. Aggregate stability tends to be most strongly influenced by the effect of soil pH on clay surface reactions. Aggregates in these soils are more stable for subsoils than for surface soils where the pH decreases and with the accumulation of illuviated clay the aggregates are more stable and persist. The accumulation of sodium that has caused sodicity in these soils occurred at a late stage of soil development under the influence of shallow saline groundwater and interflow but the acid, predominantly kaolinitic nature of the soils has helped preserve soil structure.

These salt affected soils occur in the areas that receive less than 1600 mm y^{-1} of rainfall. Accumulation of salts in the soils relates to their environmental conditions including rainfall, rock type, parent material, surface slope and land use. Soils that have high salt content in the profiles occur in the western edge of the basin where the rainfall is low with high evaporation and a shallow residual layer is present. Whereas, soils that have a lower salt content in their profiles tend to occur in the eastern part of the basin where the rainfall increases. Rainfall is a major controlling factor of the distribution of these soils. However, the distribution of the soils on the western rim of the basin is also controlled by the geological structure. Other factors that affect the distribution of salt affected soils are high evaporation and infrastructure. Therefore, the distribution of salt

affected soils tends to be widespread in the west of the basin, towards the northeast of the basin and tends to decrease towards the east of the basin.

Due to halite being a dominant salt mineral in these salt affected soils and the highly soluble salt can be easily moved by water, thus water is an important agent to dissolve, transport and distribute salts in the soil system. Salts that accumulated in the soils can be moved by both surface and subsurface water and accumulate in the lower areas or according to mobility of salts. Water is a main factor for solving the problem of salt affected soils in this region. The results of the lowest salt content, low EC ($< 4 \text{ dS m}^{-1}$) and low ESP in P16 indicate that approximately 1200 mm y^{-1} of rainfall is essential to promote sufficient leaching to move salts downwards through the profile even in the profile with the presence of salt-bearing rocks in the lower part. Salt affected areas are cut off at 1600 mm y^{-1} of rainfall.

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APPENDICES

Appendix A
Soil profile description

Pedon 1

I Information on the site

Profile symbol	: Pedon 1
Soil name	: Roi Et saline variant
Classification	: Typic Natraqualf; Coarse-loamy, mixed, isohyperthermic
Date of examination	: April 2, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 50 m west of Chaturat Chaiyaphum road at km 11 from Chaturat, Ban La Harn, Tambon La Han, Amphoe Chaturat, Chaiyaphum Province
Elevation	: Approximately 185 m (MSL)
Landform	
1. Physiographic position	: Depression strip in low terrace
2. Surrounding landform	: Slightly undulating
3. Slope on which profile site:	2%
Land use	: left idle undergrasses and shrub
Annual rainfall	: Approximately 1,239 mm
Mean temperature	: Approximately 27.5 °C
Climate	: Tropical savanna

II General information on the soil

Parent material	: Local alluvium over wash deposits.
Drainage	: Somewhat poorly drained
Permeability	: Moderate
Runoff	: Slow
Depth of ground water	: Approximately 180 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apn	0-15	Red (2.5YR 5/6); loamy sand; weak medium and coarse subangular blocky structure; loose dry, very friable moist, non-sticky and non-plastic; dark color bands of iron oxides; few thin line accumulation of iron oxide coated sands at the base of horizon; many very fine and fine vesicular pores; very fine and fine roots; very strongly acid (field pH 5.0); abrupt, smooth boundary to Apng.
Apng	15-20/40	Dark brown (7.5YR 4/2) 95% and common distinct reddish yellow (7.5YR 6/8) 5% mottles; loam; weak coarse subangular blocky structure; very hard dry, friable moist, slightly sticky and slightly plastic; common very fine and fine vesicular pores; very fine and fine roots; very strongly acid (field pH 5.0); clear, wavy boundary to Btng1.
Btng1	20/40-60	Mixed brown (7.5YR 5/2) 95%, with red (2.5YR 4/8) 5% and common distinct yellowish brown (10YR 5/8) <5% mottles; loam; moderately weak fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and few thin patchy clay coat on pore walls; few fine continuous cracks; traces of dead fine roots, few very fine and fine roots, trace of salt; medium acid (field pH 6.0); clear, wavy boundary to Btng2.
Btng2	60-87	Mixed brown (7.5YR 5/4) 80%, with yellowish (5YR 5/8) 10% and common distinct black (7.5YR 2/0) 10% mottles; sandy loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and thin patchy clay coats on pore walls; few fine discontinuous cracks; trace of fine charcoal fragments, common

		very fine and fine vesicular pore and few fine simple tubular pores, very fine and fine roots; neutral (field pH 7.0); clear, smooth boundary to Btn3.
Btn3	87-114	Mixed brown (7.5YR 5/4) >86%, with strong brown (7.5YR 5/8) 10% and common prominent red (2.5YR 4/8) <5% mottles; clay loam; moderate fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and few thin patchy clay coats on pore walls; few fine discontinuous cracks; common very fine and fine vesicular pores and few fine simple tubular pores, no roots; medium alkaline (field pH 8.0); clear, smooth boundary to Btn4.
Btn4	114-150	Mixed pink (5YR 7/3) >85% with strong brown (7.5YR 5/8) 10% and common prominent red (2.5YR 4/8) <5% mottles; sandy clay loam; moderately medium and coarse subangular blocky structure; firm moist, slightly sticky and slightly plastic; common thin patchy clay coats on ped faces and pore walls; few medium iron and aluminum oxides nodules; common very fine and few fine vesicular pores; no roots; medium alkaline (field pH 8.0); clear, smooth boundary to Btn5.
Btn5	150-172	Mixed pinkish gray (5YR 7/2) 80% with strong brown (7.5YR 5/8) 15% and common prominent red (2.5YR 4/8) 5% mottles; sandy clay loam; strong medium and coarse subangular blocky structure; hard dry, slightly firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and few thin patchy clay coats on pore walls; few medium iron and aluminum oxides nodules and few medium soft accumulation of iron and aluminum oxides; common very fine and fine vesicular and few fine simple tubular pores; no roots; moderately alkaline (field pH 8.0); clear, smooth boundary to Btn6.
Btcng	172-180+	Mixed pinkish gray (5YR 7/2) 45% with pink (5YR 7/4) 40% and common prominent strong brown (7.5YR 5/8) 15% mottles; slightly gravelly sandy clay loam; moderately fine and medium subangular blocky structure; very hard dry, slightly firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and few thin patchy clay coats on pore walls; few fine and medium iron and aluminum oxides and manganese and iron oxides concretion 10%; common very fine and fine vesicular and few fine simple tubular pores; no roots; moderately alkaline (field pH 8.0).

Pedon 2

I Information on the site

Profile symbol	: Pedon 2
Soil name	: Udon series
Classification	: Vertic Natraqualf; Fine-loamy, mixed, isohyperthermic
Date of examination	: December 18, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Saowanuch Tawornpruek, Nuttaphorn Prakongkep, Krichsana Ramsot, Saranya Norkaew and Supaluk Srithilertcharoen
Location	: Approximately 171 m North of Ban Phai - Chonnabot Road (No. 229) at 5.30 km from Ban Phai Crossroads, Ban Muang Pier, Tambon Muang Pier, Amphoe Ban Phai, Khon Kaen province
Elevation	: Approximately 152 m (MSL)
Map sheet number	: 5541 III Coordination : 48 0251534 m E., 1778128 m N.
Landform	
1. Physiographic position	: Depression on erosional plain
2. Surrounding landform	: Flat
3. Slope on which profile site:	2%

Land use	: Left idle at time of sampling (under local grasses)
Annual rainfall	: Approximately 1,200 mm
Mean temperature	: Approximately 26 °C
Climate	: Tropical savanna
Others	: Settlement with near by paddy field

II General information on the soil

Parent material	: Alluvium over residuum derived from clastic sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 170 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Ang	0-19	Mixed dark brown (10YR 3/3) 60 % and brown (10YR 4/3) 30 %, common fine distinct dark yellowish brown (10YR 4/6) and common fine prominent yellowish brown roots mottle (10YR 5/8) mottles; clay; weak very coarse angular blocky and semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; very few fine variegated sands; very few very fine and fine vesicular and few fine simple tubular pores; many very fine and fine, few medium roots; traces of dead roots; neutral (field pH 7.0); clear and smooth boundary to Btng1.
Btng1	19-38	Brown (10YR 4/3), common medium and coarse prominent strong brown (7.5YR 4/6) mottles; clay; weak very coarse angular blocky, semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on pore walls; very few fine variegated sands; few very fine, fine and medium vesicular and few fine tubular pores; common very fine and fine roots; few fine cracks; slightly acid (field pH 6.5); clear and smooth boundary to Btng2.
Btng2	38-56	Brown (10YR 4/3), many medium and coarse prominent strong brown (7.5YR 4/6) and common fine prominent red (2.5YR 4/8) mottles; clay; weak very coarse semi-angular blocky and semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; common faint clay coats on ped faces and pore walls; common cracks and very few fine variegated sands; few very fine, common fine vesicular and few fine tubular pores; few very fine and fine roots; traces of dead roots; slightly acid (field pH 6.5); clear and smooth boundary to Btng3.
Btng3	56-77	Mixed brown (10YR 4/3) 60% and light brownish gray (10YR 6/2) 10%, many medium distinct dark yellowish brown (10YR 4/6) and common fine prominent red (2.5YR 4/8) mottles; clay; weak very coarse semi-angular blocky and semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; common faint clay coats on ped faces and pore walls; few very fine variegated sands and few pressure faces; common very fine, few fine vesicular and few simple tubular pores; few very fine and fine roots; traces of dead roots and few very small soil warms; slightly acid (field pH 6.5); clear and smooth boundary to 2Btng4.
2Btng4	77-100	Mixed pale brown (10YR 6/3) 75% and light brown shifted sands (7.5YR 6/4) 5%, common medium prominent yellowish brown (10YR 5/8) and common fine prominent red (2.5YR 4/8) mottles; fine sandy clay; weak very coarse semi-angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and common faint clay bridged among sand grains; few variegated sands; very few very fine and fine vesicular and few fine simple tubular pores; few very fine and fine roots; few iron-manganese oxide nodules; slightly acid (field pH 6.5); abrupt and smooth boundary to 2Btng5.
2Btng5	100-119	Reddish yellow (7.5YR 6/6), common fine and medium prominent brownish yellow

		(10YR 6/8) and common fine prominent red (2.5YR 4/8) mottles; sandy loam; weak coarse semi-angular blocky structure; slightly sticky and slightly plastic, friable moist, soft dry; common faint clay bridged among sand grains; common variegated sands; few very fine and common fine vesicular pores; few very fine and fine roots; neutral (field pH 7.0); gradual and smooth boundary to 2Btng6.
2Btng6	119-146	Reddish yellow (5YR 6/6), common medium prominent yellowish brown (10YR 5/8) and red (2.5YR 4/8) and common fine prominent black manganese oxides (2.5Y 2.5/1) mottles; loamy sand; weak fine and medium semi-angular blocky structure; non sticky and non plastic, very friable moist, loose dry; few faint clay bridged among sand grains; common variegated sands; few very fine and fine vesicular and few tubular pores; very few very fine and fine roots; moderately alkaline (field pH 7.0); clear and smooth boundary to 2Btng7.
2Btng7 (2BCmg1)	146-175	Mixed light reddish brown (5YR 6/4) 60% and pale brown (10YR 6/3) 30%, common fine distinct dark yellowish brown (10YR 4/6) and very dark gray dead root (10YR 3/1) and common fine prominent black manganese oxides (2.5Y 2.5/1) mottles; sandy loam; moderate medium and coarse semi-angular blocky structure; slightly sticky and slightly plastic, slightly firm moist, soft dry; very few faint clay coats on pore walls and common faint clay bridged among sand grains; common variegated sands; few very fine and fine vesicular and few tubular pores; very few very fine and fine roots; common patches of variegated sands; moderately alkaline (field pH 7.0); clear and smooth boundary to 2Btng8.
2Btng8 (2BCmg2)	175-210+	Mixed light reddish brown (5YR 6/4) 85% and pale brown (10YR 6/3) 10%, common medium prominent light olive brown (2.5Y 5/6) and common fine prominent dark yellowish brown (10YR 4/4) mottles; sandy clay loam; weak medium and coarse semi-angular blocky structure; slightly sticky and slightly plastic, slightly friable moist, slightly hard dry; very few faint clay coats on pore walls and few faint clay bridged among sand grains; common variegated sands; few very fine and fine vesicular and few tubular pores; practically no roots; few iron-manganese oxide nodules; moderately alkaline (field pH 7.0).

Pedon 3

I Information on the site

Profile symbol	: Pedon 3
Soil name	: Udon series
Classification	: Vertic Natraqualf; Fine-loamy, mixed, isohyperthermic
Date of examination	: December 17, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Saowanuch Tawornpruek, Nuttaphorn Prakongkep, Krichsana Ramsoot, Saranya Norkaew and Supaluk Srithilertcharoen
Location	: Approximately 202 m North of Ban Phai - Chonnabot Road (No. 229) at 5.30 km from Ban Phai Crossroads, Ban Muang Pier, Tambon Muang Pier, Amphoe Ban Phai, Khon Kaen province
Elevation	: Approximately 152 m (MSL)
Map sheet number	: 5541 III Coordination : 48 0251599 m E., 1778144 m N.

Landform

1. Physiographic position : Depression on erosional plain
2. Surrounding landform : Flat
3. Slope on which profile site: 2%

Land use : Left idle under salt tolerant grasses
 Annual rainfall : Approximately 1,200 mm
 Mean temperature : Approximately 26 °C
 Climate : Tropical savanna
 Others : Settlement mainly

II General information on the soil

Parent material : Alluvium
 Drainage : Poorly drained
 Permeability : Slow
 Runoff : Slow
 Depth of ground water : Approximately 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Ang	0-21	Dark grayish brown (10YR 4/2), common medium and coarse prominent strong brown (7.5YR 5/6) mottles; clay; weak very coarse angular blocky and semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; few traces of dead roots and common large vertical cracks; few very fine, fine and very fine and medium vesicular and few fine simple tubular pores; many very fine and fine roots; few fine cracks; slightly acid (field pH 6.5); clear and smooth boundary to Btn1.
Btn1	21-41	Dark grayish brown (10YR 4/2), common fine and medium prominent yellowish brown (10YR 5/8) mottles; clay; moderate medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm moist, very hard dry; few faint clay coats on pore walls and few faint clay bridged among sand grains; very few translocated very fine sands patched in tubular pores; common very fine and fine vesicular and few tubular pores; common very fine and fine roots; few fine cracks; slightly acid (field pH 6.5); clear and smooth boundary to Btn2.
Btn2	41-66	Mixed light gray (10YR 7/2) 40% and dark grayish brown (10YR 4/2) 20%, many fine and medium distinct yellowish brown (10YR 5/6) and common fine and medium prominent yellowish brown (10YR 5/8) mottles; clay; moderate medium and coarse angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; common faint clay coats on ped faces and pore walls; very few very fine variegated sands; few very fine and common fine vesicular and few fine tubular pores; few very fine and fine roots; trace of dead roots; slightly acid (field pH 6.5); clear and smooth boundary to Btn3.
Btn3	66-88	Mixed light gray (10YR 7/2) 35% and gray (10YR 5/1) 30%, common fine and medium prominent yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8) and common fine and medium distinct dark yellowish brown (10YR 4/4) mottles; clay; moderate medium and coarse angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; common distinct clay coats on ped faces and pore walls; very few very fine variegated sands; few very fine and common fine vesicular and few fine tubular pores; few very fine and fine roots; trace of dead roots; slightly acid (field pH 6.5); clear and smooth boundary to Btn4.
Btn4	88-108	Mixed gray (2.5Y 6/1) 50% and grayish brown (10YR 5/2) 10%, many fine and medium prominent yellowish brown (10YR 5/8) and common fine prominent light olive brown (2.5Y 5/6) mottles; clay; moderate fine and medium angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; common distinct clay coats on ped faces and pore walls; few fine pressure faces,

		few fine variegated sands and fine cracks; few very fine and common fine vesicular and few fine tubular pores; few very fine and fine roots; common large slickenside and common trace of dead roots; neutral (field pH 7.0); clear and smooth boundary to Btng5.
Btng5	108-132	Gray (2.5Y 6/1), common fine and medium prominent yellowish brown (10YR 5/8) and dark yellowish brown (10YR 4/6) mottles; silty clay; moderate medium and coarse angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on ped faces and pore walls; few fine pressure faces; very few very fine and fine vesicular and few fine tubular pores; few very fine and fine roots; common large slickenside and few fine spots of manganese oxides accumulates; neutral (field pH 7.0); clear and smooth boundary to Btng6.
Btng6	132-165	Gray (10YR 5/1), common fine and medium prominent red (10R 4/8) and yellowish brown (10YR 5/8) mottles; silty clay; moderate fine and medium semi-angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on ped faces and pore walls; few fine spots of manganese oxide nodule; very few very fine and few fine vesicular and tubular pores; few very fine and fine roots and root cluster; common large slickenside; moderately alkaline (field pH 7.0); clear and smooth boundary to Btng7.
Btng7	165-184	Mixed gray (10YR 5/1) 60% and very dark grayish brown (10YR 3/2) 20%, common fine and medium prominent yellowish brown (10YR 5/8) and red (2.5YR 4/8) mottles; silty clay; moderate medium and coarse semi-angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on ped faces and pore walls; few fine variegated sand and few pressure faces; very few very fine and few fine vesicular and tubular pores; few very fine and fine roots; few large slickenside; moderately alkaline (field pH 7.0); clear and smooth boundary to Btng8.
Btng8	184-202+	Mixed gray (10YR 5/1) 40% and very dark gray (10YR 3/1) 30%, many medium prominent red (2.5YR 4/8) and common fine and medium prominent yellowish brown (10YR 5/8) mottles; silty clay; weak very coarse semi-angular blocky and semi-massive structure; very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on ped faces and pore walls; very few fine variegated sand and few pressure faces; few very fine and fine vesicular and few tubular pores; few very fine and fine roots; common large slickenside; moderately alkaline (field pH 7.0).

Pedon 4

I Information on the site

Profile symbol	: Pedon 4
Soil name	: Roi Et, saline variant
Classification	: Typic Natraqualf; Coarse-loamy, mixed, ishyperthermic
Date of examination	: April 18, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsoot and Saranya Norkaew
Location	: Approximately 400 m west of Phera Yuen-Mancha Khiri Road (No. 2062) at 3 km from Phera Yuen Crossroads, Ban Bo Kae, Tambon Kham Pom, Amphoe Phera Yuen, Khon Kaen province
Elevation	: Approximately 178 m (MSL)
Map sheet number	: 5541 IV Coordination : 48 0248677 m E., 1804999 m N.

Landform

1. Physiographic position : Low terrace (Mid-low terrace)
2. Surrounding landform : Flat
3. Slope on which profile site: 1%

Land use : Paddy/ Left idle because of salt effect
 Annual rainfall : Approximately 1,300 mm
 Mean temperature : Approximately 26 °C
 Climate : Tropical savanna
 Others : Agricultural and settlement development

II General information on the soil

Parent material : Wash over residuum derived from clastic sedimentary rock
 Drainage : Poorly drained
 Permeability : Slow
 Runoff : Slow
 Depth of ground water : Approximately 195 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-12	Mixed light brownish gray (10YR 6/2) 60 %, reddish yellow (7.5YR 7/6) 30% and grayish brown (10YR 5/2) 10%; sandy loam; moderate fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, slightly friable moist, slightly hard dry; common clay bridges among sand grains; many variegated sands; few very fine, fine and medium vesicular pores; practically no roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Bng.
Bng	12-37	Reddish yellow (7.5YR 7/6), common fine prominent brownish yellow (10YR 6/8) and common fine distinct reddish yellow (7.5YR 6/8) mottles; loamy sand; weak medium and coarse semi-angular blocky structure; non-sticky and non-plastic, firm moist, loose dry; many variegated sands; few very fine, fine and medium vesicular pores; practically no roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng1.
Btng1	37-60	Reddish yellow (7.5YR 7/6), few fine and medium faint strong brown (7.5YR 5/6) and common medium distinct brownish yellow (10YR 6/8) mottles; sandy loam; moderate fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, slightly friable moist, slightly hard dry; few faint clay coats on pore walls and common faint clay bridges among sand grains; few manganese oxides concretions and nodules, common variegated sands; very few very fine, common fine and few medium vesicular pores; practically no root; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng2.
Btng2	60-76	Light brown (7.5YR 6/4), common medium prominent yellowish brown (10YR 5/8) mottles; sandy clay loam; moderate fine and medium angular blocky structure; slightly sticky and moderately plastic, firm moist, slightly hard dry; common distinct clay bridges among sand grain and few faint clay coats on pore walls; common variegated sand grains; very few very fine and few fine vesicular pores; practically no root; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng3.
Btng3	76-100	Pink (7.5YR 7/4), many medium prominent brownish yellow (10YR 6/8) and yellow (10YR 7/8) mottles; slightly gravelly sandy clay loam; strong fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and clay bridges among sand grains; common variegated sand grains; few large carbonate cobbles, few dark spots of manganese oxides; few very fine and common fine vesicular and few fine simple tubular pores; practically no root; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng4.

Btng4	100-128	Brownish yellow (10YR 6/6); sandy clay loam; moderate fine and medium semi-angular blocky structure; slightly sticky and moderately plastic, slightly firm moist, slightly hard dry; common faint clay bridges among sand grains; common variegated sand grains, few large carbonate cobbles, common dark spots of manganese oxides; few very fine and fine vesicular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng5.
Btng5	128-140	Light brown (7.5YR 6/4), common medium and few fine prominent brownish yellow (10YR 6/8) mottles; sandy loam; moderate fine and medium subangular blocky structure; slightly sticky and moderately plastic, slightly firm moist, slightly hard dry; common faint clay bridges among sand grains; common variegated sand grains, few small manganese oxides nodules; few very fine and fine vesicular pores; practically no roots; moderately alkaline (field pH 8.0); abrupt and smooth boundary to 2Btng6.
2Btng6	140-170	Mixed pink (7.5YR 7/4) 45% and pinkish gray (7.5YR 7/2) 30%, many medium prominent brownish yellow (10YR 6/8) and yellowish brown (10YR 5/8) mottles; sandy clay loam; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls and clay bridges among sand grains; common dark spots of manganese oxides and variegated sand grains; few very fine and fine vesicular pores; practically no roots; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng7.
2Btng7	170-190+	Pink (7.5YR 7/4), common medium prominent brownish yellow (10YR 6/8) mottles; sandy clay loam; moderate fine and medium semi-angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and clay bridges among sand grains; common dark spots of manganese oxides nodules and concretions (soft) and common variegated sands; few very fine and fine vesicular pores; practically no roots; few fine cracks; moderately alkaline (field pH 8.0).

Pedon 5

I Information on the site

Profile symbol	: Pedon 5
Soil name	: Roi Et, saline variant
Classification	: Typic Natraqual; Fine- loamy, mixed, isohyperthermic
Date of examination	: June 9, 2002
Described by	: Irb Kheoruenromne, Piboon Kanghae, Saowanuch Tawornpruek, Chutharmard Kaewmano, Napaporn Wongpokhom, Niwat Anongrak, Tanapol Srisupha-olarn
Location	: Approximately 50 m South of Dan Khun Thot-Chatturat Road (No. 201) at 7.5 km from Dan Khun Thot Crossroads, Ban Nong Bua Takiat, Tambon Nong Bua Takiat, Amphoe Dan Khun Thot, Nakhon Ratchasima province
Elevation	: Approximately 203 m (MSL)
Map sheet number	: 5339 I Coordination : 47 799696 m E., 1689674 m N.
Landform	
1. Physiographic position	: Low terrace
2. Surrounding landform:	Gently undulating
3. Slope on which profile site:	1%
Land use	: Rice growing; left idle under local grasses
Annual rainfall	: Approximately 1,035 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna

Others : Agricultural and village settlement

II General information on the soil

Parent material : Local alluvium and wash over residuum derived from sedimentary rock
 Drainage : Poorly drained
 Permeability : Slow
 Runoff : Slow
 Depth of ground water : Approximately 140 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng1	0-13	Mixed dark brown (10YR 4/3) 50% and brown (7.5YR 5/4) 50%, few fine prominent yellowish red (5YR 5/6) mottles; sandy loam; moderately weak fine and medium subangular blocky structure; non-sticky and non-plastic, very friable moist, slightly hard dry; few variegated sands; few very fine, fine and common medium vesicular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Apng2.
Apng2	13-28	Light brown (7.5YR 6/4), common fine distinct yellowish red (5YR 4/6) mottles; sandy loam; moderate fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, friable moist, slightly hard dry; few variegated sands; few very fine, fine and common medium vesicular pores; practically no roots; few spot accumulations of manganese oxides; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng1.
Btng1	28-53	Mixed brown (7.5YR 5/4) 70% and grayish brown (10YR 5/2) 30%, redox concentration of distinct black (7.5YR 2/0) (Mn-oxides) mottles; sandy loam; moderate fine and medium semi-angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; few fine clear clay coats on pore walls and some clay bridges among sand grains, few fine variegated sands; few very fine and fine vesicular pores and fine simple tubular pores; no roots; concentrated manganese oxides nodules (7.5YR 2/0) mostly on upper part; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng2.
Btng2	53-80	Mixed light brownish gray (10YR 6/2) 80% and brown (7.5YR 5/4) 20%, few fine distinct strong brown (7.5YR 5/8) and redox concentration mottles; sandy loam; strong medium and coarse angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry; common clear clay coats on pore walls and ped faces with some clay bridges, few fine variegated sands with patch of sands cut vertically down to approximately 2Btng4; few very fine and fine vesicular pores and few fine simple tubular pores; no roots; some dispersive accumulation of manganese oxides nodules (7.5YR 2/0) throughout 2Btng layers; moderately alkaline (field pH 8.0); abrupt and smooth boundary to 2Btng1.
2Btng1	80-100	Light brownish gray (10YR 6/2), many medium distinct strong brown (7.5YR 5/8) and few fine distinct strong brown (7.5YR 4/6) mottles; loam; strong medium and coarse angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry; common clear clay coats on pore walls and ped faces with some clay bridges, few fine variegated sands with patch of sands cut vertically down to approximately 2Btng4, few fine cracks; few very fine and fine vesicular pores and few fine simple tubular pores; no roots; some dispersive accumulation of manganese oxides nodules (7.5YR 3/0) throughout 2Btng layers; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng2.
2Btng2	100-120	Mixed pale brown (10YR 6/3) 70% and light gray (10YR 7/2) 30%, common fine distinct strong brown (7.5YR 5/8) mottles; clay loam; strong medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm

		moist, very hard dry; common clear clay coats on pore walls and ped faces with some clay bridges, few fine variegated sands with patch of sands cut vertically down to approximately 2Btng4 and few fine variegated sands; few very fine, fine and medium vesicular pores and few fine simple tubular pores; no roots; some dispersive accumulation of manganese oxides nodules (7.5YR 3/0) throughout 2Btng layers with large concentric nodules of Na_2CO_3 ; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng3.
2Btng3	120-145	Mixed pale brown (10YR 6/3) 60% and light gray (10YR 7/2) 40%, common fine distinct strong brown (7.5YR 4/6) and few fine distinct strong brown (7.5YR 5/8) mottles; clay loam; strong medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common clear clay coats on pore walls and ped faces with some clay bridges, few fine variegated sands with patch of sands cut vertically down to approximately 2Btng4 and few fine variegated sands; few very fine, fine and medium vesicular pores and few fine simple tubular pores; no roots; some dispersive accumulation of manganese oxides nodules (7.5YR 3/0) throughout 2Btng layers with large concentric nodules of Na_2CO_3 and increase amount of manganese oxide nodules; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng4.
2Btng4	145-178	Mixed pale brown (10YR 6/3) 50% and light gray (10YR 7/2) 50%, common fine distinct strong brown (7.5YR 4/6) and common fine distinct strong brown (7.5YR 5/8) mottles; clay loam; strong medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common clear clay coats on pore walls and ped faces with some clay bridges and common large clay patches in the matrix, few fine variegated sands with patch of sands cut vertically down to approximately 2Btng4, common fine cracks; very few very fine and fine vesicular pores and few fine simple tubular pores; no roots; some dispersive accumulation of manganese oxides nodules (7.5YR3/0) throughout 2Btng layers with large concentric nodules of Na_2CO_3 and increase amount of manganese oxides nodules; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng5.
2Btng5	178-200+	Light brownish gray to light gray (10YR 6/2-7/2), many fine distinct strong brown (7.5YR 4/6) and few fine distinct gray (7.5YR 5/0) mottles; clay loam; strong medium and coarse angular blocky structure; moderately sticky and moderately plastic, firm moist, very hard dry; common clear clay coats on ped faces and pore walls and common clay patches in the matrix, few fine variegated sands, common fine cracks; very few very fine and fine vesicular pores; no roots; moderately alkaline (field pH 8.0).

Pedon 6

I Information on the site

Profile symbol	: Pedon 6
Soil name	: Phimai, saline variant
Classification	: Typic Natraqual; Fine, mixed, isohyperthermic
Date of examination	: June 8, 2002
Described by	: Irb Kheoruenromne, Piboon Kanghae, Saowanuch Tawornpruek, Chutharmard Kaewmano, Napaporn Wongpokhom, Niwat Anongrak, , Tanapol Srisupha-olarn,
Location	: Approximately 50 m South of Dan Khun Thot-Chatturat Road (No 201) at 9.8 km from Dan Khun Thot Crossroads, Ban Yai, Tambon Nong Bua Takiat, Amphoe Dan Khun Thot, Nakhon Ratchasima province
Elevation	: Approximately 185 m (MSL)

Map sheet number	: 5339 I	Coordination	: 47 800719 m E., 1691587 m N.
Landform			
1. Physiographic position	: Lower part of low terrace		
2. Surrounding landform	: Gently undulating		
3. Slope on which profile site	: 3%		
Land use	: Paddy rice periodically; Neem (<i>Azadirachta indica</i> A. Juss. Var.), Combretum (<i>Combretum quadranglaer</i> Kurz.), Local grasses		
Annual rainfall	: Approximately 1,035 mm		
Mean temperature	: Approximately 27 °C		
Climate	: Tropical savanna		
Others	: Agriculture		

II General information on the soil

Parent material	: Riverine alluvium
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 190 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg1	0-15	Dark grayish brown (10YR 4/2), common fine prominent gray (7.5YR 5/0) mottles; clay loam; strong medium and coarse subangular blocky structure; moderately sticky and very plastic, very firm moist, extremely hard dry; common very fine, fine and few medium vesicular pores; few very fine, fine and medium roots; few traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Apg2.
Apg2	15-32/36	Dark gray (10YR 4/1), common fine distinct strong brown (7.5YR 4/6) mottles; clay; strong medium and coarse angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry; common very fine, fine, few medium and few fine vesicular pores; few very fine, fine and medium roots; few fine cracks and few traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to ABng.
ABng	36-57	Dark gray (10YR 4/1), few fine distinct strong brown (7.5YR 4/6) mottles; silty clay; strong medium and coarse angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry; few fine pressure faces; few very fine, fine vesicular pores and few fine simple tubular pores; very few very fine and fine roots; few fine cracks; neutral (field pH 7.0); clear and smooth boundary to Btng1.
Btng1	57-87	Dark gray (10YR 4/1); clay; moderate fine and medium angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry; common distinct pressure faces; few very fine, fine and medium vesicular pores; practically no roots; few fine cracks; moderately alkaline (field pH 8.0); gradual and smooth boundary to Btng2.
Btng2	87-115	Dark gray (10YR 4/1); clay; moderate fine and medium angular blocky structure; moderately sticky and very plastic, very firm moist, very hard dry, common distinct pressure faces; few very fine, fine and medium vesicular pores and few fine simple tubular pores; practically no roots; few fine cracks; neutral (field pH 7.0); clear and smooth boundary to Btng3.
Btng3	115-144	Gray (10YR 5/1), many medium distinct strong brown (7.5YR 4/6) mottles; sandy clay; moderate fine and medium angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; very few clear clay coats on pore walls; common very fine, few fine and medium vesicular pores and few fine simple tubular pores; practically no roots; neutral (field pH 7.0); abrupt and smooth boundary to Btng4.

Btng4	144-160/162	Brown (7.5YR 5/2), few fine distinct strong brown (7.5YR 5/8) mottles; loamy sand; weak fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, very friable moist, slightly hard dry; very few clear clay coats on pore walls and common clay bridges among sand grains; few variegated sands; few very fine, fine and medium vesicular pores; no roots; neutral (field pH 7.0); abrupt and smooth boundary to Btng5.
Btng5	162-195+	Grayish brown (10YR 5/2), many fine distinct strong brown (7.5YR 5/8, 7.5YR 4/6,) mottles; sandy clay loam; moderate fine and medium semi-angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; common clear clay coats on pore walls and few clay bridges among sand grains; few variegated sands; very few very fine, fine and medium vesicular pores; no roots; few fine cracks; neutral (field pH 7.0).

Pedon 7

I Information on the site

Profile symbol	: Pedon 7
Soil name	: Roi Et Saline variant
Classification	: Typic Natraqual; Fine-loamy, mixed, isohyperthermic
Date of examination	: March 29, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 80 m east of road 2148 from nong Sroung to Dan Khuntot, approximately at km 3, Ban Nong Sroung, Tambon Nong Sroung, Amphoe Kam Tale So, Nakhon Ratchasima Province.
Elevation	: Approximately 192 m (MSL)
Landform	
1. Physiographic position	: Depression on low terrace
2. Surrounding landform	: Slightly undulating
3. Slope on which profile site:	2%
Land use	: left idle
Annual rainfall	: Approximately 1,130 mm
Mean temperature	: Approximately 26.6°C
Climate	: Tropical savanna

II General information on the soil

Parent material	: Local alluvium and wash deposits
Drainage	: Poorly drained
Permeability	: Moderate
Runoff	: Moderate
Depth of ground water	: Approximately 80 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng1	0-20/35	Yellowish red (5YR 4/6) 60% common faint reddish brown (5YR 5/3) 20% and common red (2.5YR 4/8) 5% mottles; sandy; very weak fine and medium subangular blocky structure; loose dry, loose moist, non-sticky and non-plastic common; laminating accumulation of salt iron and aluminum pores; very few fine roots; slightly acid (field pH 6.5); abrupt, wavy boundary to Apng2

Apng2	20/35-55	Mixed very dark gray brown (10YR 3/2) 90% with black (7.5YR 2/0) 5% and common distinct dark yellowish brown (10YR 3/6) <5% mottles; loam; moderate fine and medium subangular blocky structure; slightly hard dry, very friable moist, slightly sticky and slightly plastic; common very fine and fine vesicular and few fine simple tubular pores; common very fine and fine roots; neutral (field pH 7.0); clear, wavy boundary to Btng1.
Btng1	55-76/81	Mixed light reddish brown (5YR 6/3) >90% with black (7.5YR 2/0) 5% and common distinct dark gray (10YR 3/0) <5% mottles; sandy loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; few clay bridges on sand grains; common fine iron and manganese oxides concretions; many very fine and fine vesicular and few fine simple tubular pores; few fine roots; neutral (field pH 7.0); gradual, wavy boundary to Btng2.
Btng2	76/81-115/118	Mixed light reddish brown (5YR 6/3) 90% with black (5YR 2/1) 5% and common prominent yellowish brown (10YR 5/8) 5% mottles; sandy loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; common clay bridges and very fine thin patchy clay coats on tubular pore walls; common variegated sand and few fine manganese and iron oxides accumulation; common very fine and fine vesicular and common fine dendritic tubular pores; very fine roots and trace of dead fine roots; neutral (field pH 7.0); gradual, wavy boundary to Btng3.
Btng3	115/118-130/137	Mixed pink (5YR 7/4) 90% with black (5YR 2/1) 5% and common prominent yellowish brown (10YR 5/8) 5% mottles; sandy clay loam; moderate weak fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; common clay bridges and few thin patchy clay coats on tubular pore walls; common variegated sand, few medium iron and manganese oxide soft nodules; few fine spot accumulation of organic matter; common very fine and fine vesicular and few fine simple tubular pores; very few fine roots; neutral (field pH 7.0); gradual, wavy boundary to Btng4.
Btng4	130/137-150/163	Mixed pink (5YR 7/4) 80% with dark reddish brown (5YR 2/2) 7% and common distinct strong brown (7.5YR 5/8) 5% mottles; sandy clay loam; weak coarse angular and subangular blocky structure; friable moist, slightly sticky and slightly plastic; common clay bridges and few thin clay coat accumulation of few fine iron and manganese soft nodules; common fine and few very fine vesicular and few fine simple tubular pores; very few fine roots; moderately alkaline (field pH 8.0); clear, wavy boundary to Btng5.
Btng5	150/163-190+	Pink (7.5YR 7/4) 90% and common prominent dark brown (7.5YR 3/4) 10% mottles; sandy clay loam; moderately weak medium and weak coarse angular blocky structure; friable moist, slightly sticky and slightly plastic; common clay bridges on sand grain; many accumulation iron and manganese oxide soft fine nodules; common fine cracks and few quartz grains; common fine vesicular pores; no roots; moderately alkaline (field pH 8.0).

Pedon 8

I Information on the site

Profile symbol	: Pedon 8
Soil name	: Roi Et saline variant
Classification	: Typic Natraqualf; Fine-loamy, mixed, isohyperthermic
Date of examination	: March 28, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 50 m South of Road 2068 from Non Thai to Nong Sroung; approximately 12 km from Non Thai, Ban Wang, Amphoe Non Thai, Nakhon Ratchasima Province
Elevation	: Approximately 165 m (MSL)
Landform	
1. Physiographic position	: Depression on low terrace
2. Surrounding landform	: slightly undulating
3. Slope on which profile site:	2%
Land use	: Disturbed paddy field
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 26.2°C
Climate	: Tropical savanna

II General information on the soil

Parent material	: Alluvium over residuum
Drainage	: Somewhat poorly drained
Permeability	: Moderate
Runoff	: Moderately slow
Depth of ground water	: Approximately 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-20	Dark reddish gray (5YR 4/2) 60% many distinct pink (5YR 7/3) 30% and common distinct dark brown (7.5YR 3/2) 10% mottles; loam; moderate fine and medium subangular blocky structure; slightly hard dry, friable moist, slightly sticky and slightly plastic; common sand accumulation pockets; common very fine vesicular pores; many very fine and fine roots; medium acid (field pH 6.0); abrupt, smooth boundary to Btng1.
Btng1	20-45/50	Gray (5YR 5/1) 95% and common prominent black (7.5YR 2/0) 5% mottles; loam; moderate fine and medium angular and subangular blocky structure; slightly hard dry, friable moist, slightly sticky and slightly plastic; few clay bridge and common thin patchy clay coat on pore walls; few medium iron and manganese oxides nodules and common fine cracks; common very fine and fine vesicular and fine simple tubular pores; common very fine and few fine roots; medium acid (field pH 6.0); clear, wavy boundary to Btng2.
Btng2	45/50-65/70	Light reddish brown (5YR 6/8) 95% and common prominent black (10YR 2/1) 5% mottles; loam; moderate fine and medium subangular blocky structure; hard dry, slightly firm moist, slightly sticky and slightly plastic; common clay coats on ped faces of pore wall; some few medium rounded lime nodules accumulation and common fine cracks; many very fine and fine vesicular and common fine simple tubular pores; few very fine and fine roots; medium acid (field pH 6.0); abrupt, wavy boundary to Btng3.
Btng3	65/70-100	Mixed pink (5YR 7/3) 85% with black (5YR 2/1) 10% and common distinct and reddish yellow (7.5YR 7/8) 5% mottles; slightly gravelly loam; moderate fine and medium subangular blocky structure; slightly

		firm moist, slightly sticky and slightly plastic; common clay bridges and few thin patchy clay coats on ped faces and pore walls; few fine and medium accumulation of iron-manganese oxide and lime nodules; many very fine and fine vesicular and common fine simple tubular pores; few very fine and fine roots; slightly acid (field pH 6.5); abrupt, wavy boundary to Btn4.
Btng4	100-112/120	Light reddish brown (5YR 6/3) 40% many faint reddish brown (5YR 5/4) 30%, common distinct brown (10YR 4/2) 20% and common distinct strong brown (7.5YR 5/6) 10% mottles; very fine sandy loam; moderate fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic; common clay bridges and few thin patchy clay coat on ped faces and pore walls; few fine krotovinas and few fine and accumulation; common fine vesicular and simple tubular pores; few very fine roots; slightly acid (field pH 6.5); abrupt, wavy boundary to Btn5.
Btng5	112/120-130/138	Light reddish brown (5YR 5/4) 60% many faint pink (5YR 7/3) 30% and common distinct dark reddish brown (5YR 3/2) 10% mottles; loam; moderate fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic; few fine clay bridge and few thin patchy clay coat on pore walls; few medium iron-aluminum oxide soft concretion; common fine cracks; common very fine and fine vesicular and fine simple tubular pores; very fine and fine roots; slightly acid (field pH 6.5); abrupt, wavy boundary to Btn6.
Btng6	138-160/170	Pink (5YR 7/4) 60% many faint pink (5YR 7/3) 30% and common distinct dark reddish brown (5YR 3/2) 10% mottles; clay loam; moderate fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic; few thin patchy clay coat on ped faces and pore walls; few medium iron-aluminum oxide soft concretion and common fine cracks; common very fine simple and dendritic tubular and common fine vesicular pores; very fine and fine roots; slightly acid (field pH 6.5); abrupt, wavy boundary to 2Cng1.
2Cng1	160/170-172/175	Mixed yellowish red (5YR 5/8) 60% with pinkish gray (7.5YR 6/2) 70%, common distinct red (2.5YR 4/8) 15% and common prominent black (2.5YR 2/0) <5% mottles; sandy clay loam; weak fine and medium subangular blocky structure; very firm moist, slightly sticky and slightly plastic; few quartz gravel and manganese oxide accumulation; common fine vesicular pores; no roots; slightly acid (field pH 6.5); abrupt, wavy boundary to 2Cng2.
2Cng2	172/175-200+	Red (2.5YR 4/8) 85% and common faint dark reddish brown (2.5YR 2/4) mottles; clay; weak coarse angular subangular blocky structure; partially retaining rock structure; slightly firm moist, slightly sticky and slightly plastic; few pressure faces and common fine cracks; common fine vesicular and few fine simple tubular pores; no roots; neutral (field pH 7.0).

Pedon 9

I Information on the site

Profile symbol	: Pedon 9
Soil name	: Chatturat saline variant
Classification	: Typic Natraqualf; Fine, mixed, isohyperthermic
Date of examination	: March 29, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 120 m East of Road 2150 between Non Thai to Amphoe Kong; approximately 20 km from Non Thai, near Ban Kham Sakae Saeng, about 150 m, Ban Kham, Amphor Kham Sakae Sang, Nakhon Ratchasima Province
Elevation	: Approximately 184 m (MSL)
Landform	
1. Physiographic position	: Lower erosional terrace
2. Surrounding landform	: Almost flat
3. Slope on which profile site:	1%
Land use	: Paddy rice, left idle under grass at time of sampling
Annual rainfall	: Approximately 1,180 mm
Mean temperature	: Approximately 26.2 °C
Climate	: Tropical savanna

II General information on the soil

Parent material	: Local alluvium derived from basic rocks overlying residuum
Drainage	: Some what poorly drained
Permeability	: Moderate
Runoff	: Slow
Depth of ground water	: Approximately 180 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	1-15/37	Dark reddish brown (5YR 3/2); clay loam; strong medium and coarse angular subangular blocky structure; very hard dry, firm moist, slightly sticky and slightly plastic; common very fine and fine vesicular and few fine tubular pores; common very fine and fine roots; moderately alkaline (field pH 8.0) clear, wavy boundary to Btng1.
Btng1	15/37-40	Dark brown (7.5YR 4/2) 95% and common prominent reddish yellow (5YR 6/8) 5% mottles; clay; strong medium coarse angular and subangular blocky structure; very hard dry, firm moist, slightly sticky and slightly plastic; few thin patchy clay coats on tubular pore walls; common fine soft manganese oxide nodules; common fine vesicular and simple tubular pores; few very fine and fine roots; moderately alkaline (field pH 8.0) clear, wavy boundary to Btng2.
Btng2	40-72/73	Reddish brown (5YR 4/4) 92% and common prominent reddish yellow (5YR 6/8) 8% mottles; clay; strong fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic; few thin patchy clay coats on ped faces and pore walls; common fine lime fragments; common fine vesicular and simple tubular pores; very few very fine roots; moderately alkaline (field pH 8.0) abrupt, wavy boundary to Ckng1.

2Ckng1	73-96	Reddish brown (5YR 4/4) 90% and common distinct reddish yellow (5YR 6/8) 10% mottles; very gravelly clay; weak fine and medium subangular blocky structure; parting along coarse fragment surfaces; slightly firm moist, slightly sticky and slightly plastic (fine earth); abundant medium and coarse lime nodules and calcareous siltstone fragments; common fine vesicular pores; no roots; moderately alkaline (field pH 8.0) clear, wavy boundary to Ckng2.
2Ckng2	96-123/126	Reddish brown (5YR 5/4) 95% and common prominent reddish yellow (7.5YR 6/8) 5% mottles; very gravelly clay; moderate weak fine and medium subangular blocky structure, parting along coarse fragment surface; slightly firm moist, slightly sticky and slightly plastic (fine earth); few thin patchy clay coats on pore wall and nodule surface; abundant medium and coarse lime nodules and calcareous siltstone fragments, many large lime nodules and calcareous siltstone fragments; common fine vesicular pores; no roots; moderately alkaline (field pH 8.0) clear, wavy boundary to Ckng3.
2Ckng3	123/126-190+	Red (2.5YR 5/8) 95%; very gravelly sandy clay; weak fine and medium subangular blocky structure, parting along coarse fragment surface; slightly firm moist, slightly sticky and slightly plastic (fine earth); abundant, many large lime nodules and calcareous siltstone fragments, common fine vesicular pores; no roots; moderately alkaline (field pH 8.0)

Pedon 10

I Information on the site

Profile symbol	: Pedon 10
Soil name	: Kula Ronghai; Loamy-skeletal variant
Classification	: Typic Natraqual; Loamy-skeletal, mixed, isohyperthermic
Date of examination	: June 12, 2002
Described by	: Irb Kheoruenromne, Piboon Kanghae, Saowanuch Tawornpruek, Chutharmard Kaewmano, Napaporn Wongpokhom, Niwat Anongrak, Tanapol Srisupha-olarn,
Location	: Approximately 150 m North of Mittraparp road (No.2) at km 37 from Nakhon Ratchasima, Ban Muang Thi, Tambon Don Chomphu, Amphoe Non Sung, Nakhon Ratchasima province
Elevation	: Approximately 162 m (MSL)
Map sheet number	: 5439 II Coordination : 48 213924 m E., 1680127 m N.
Landform	
1. Physiographic position	: Low erosional terrace
2. Surrounding landform	: Gently undulating
3. Slope on which profile site	: 2%
Land use	: Paddy rice, Left idle under local grasses, Areca palm, <i>Azima sarmentosa</i> Benth, Bamboo (<i>Bambusa</i> sp.), Neem (<i>Azadirachta indica</i> A. Juss. var.), Nut grass (<i>Cyperus rotundus</i> L.)
Annual rainfall	: Approximately 1035 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural

II General information on the soil

Parent material	: Residuum derived from sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow

Depth of ground water : Approximately 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-12/15	Dark grayish brown (10YR 4/2), many medium prominent yellowish red (5YR 4/6) and common coarse prominent red (2.5YR 4/6) mottles; loamy sand; moderately weak fine and medium subangular blocky structure; slightly sticky and slightly plastic, friable moist, soft dry; many traces of dead roots and few fine cracks; common very fine, few fine vesicular pores and few fine simple tubular pores; common very fine, few fine and medium roots; few faint manganese oxides concretions (7.5YR 2/0), few fine variegated sands; slightly acid (field pH 6.5); abrupt and smooth boundary to Btcng.
Btcng	15-32/36	Grayish brown (10YR 5/2), many fine distinct strong brown (7.5YR 4/6) and few medium prominent yellowish red (5YR 4/6) mottles; extremely gravelly sandy loam; strong fine and medium subangular blocky structure; slightly sticky and moderately plastic, friable moist, hard dry; few clear clay coats on pore walls and many clay bridges among sand grains; abundant fine manganese oxides concretions (7.5YR 2/0), common pressure faces; few very fine and common fine vesicular pores and few fine simple and dendritic tubular pores; very few very fine and fine roots; many traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng1.
Btng1	36-60	Grayish brown (10YR 5/2), many medium distinct yellowish brown (10YR 5/8) and common medium distinct strong brown (7.5YR 4/6) mottles; very gravelly sandy clay loam; strong fine and medium subangular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; common clear clay coats on ped faces and pore walls and many clay bridges among sand grains; common manganese oxides concretions (2.5YR 3/4) and soft accumulations; few fine variegated sands; few very fine, fine and medium vesicular pores and few fine simple tubular pores; very few fine roots; many traces of dead roots, few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng2.
Btng2	60-85	Light brownish gray (10YR 6/2), many fine distinct yellowish brown (10YR 5/8) and common medium prominent red (2.5YR 4/6) mottles; gravelly sandy clay loam; strong fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; few clear clay coats on pore walls and ped faces and many clay bridges among sand grains; few manganese oxides concretions (7.5YR 2/0) and soft accumulations, many fine variegated sands; few very fine, fine and medium vesicular pores and few fine simple tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); gradual and smooth boundary to Btng3.
Btng3	85-106	Mixed light brownish gray (10YR 6/2) 80%, and light gray (10YR 7/1) 20%, many fine faint grayish brown (10YR 5/2) and common fine prominent red (2.5YR 4/6) mottles; slightly gravelly sandy clay loam; strong fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; few clear clay coats on pore walls and ped faces and many clay bridges among sand grains; few manganese oxides concretions (7.5YR 2/0) and soft accumulations, many fine variegated sands; very few very fine, few fine and medium vesicular pores, and few fine simple tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng4.
Btng4	106-125/130	Mixed light brownish gray (10YR 6/2) 80%, and light gray (10YR 7/1) 20%, many fine distinct yellowish brown (10YR 5/8) and many medium prominent red (2.5YR 4/6) mottles; sandy clay loam; strong fine and medium angular blocky structure; moderately sticky and very plastic, very firm moist, hard dry; common clear clay coats on pore walls and ped faces; few manganese oxides, iron oxides and Mn-Fe

		oxides spot accumulations; few very fine and fine vesicular pores, and few fine simple tubular pores; practically no roots; few fine variegated sands; moderately alkaline (field pH 8.0); abrupt and wavy boundary to BCng.
BCng	130-156	Light gray (10YR 7/1), many coarse prominent red (2.5YR 4/6) and common medium distinct yellowish brown (10YR 5/8) mottles; sandy clay loam; strong medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; few clear clay coats on pore walls and along thin beds of rock structure, spots of broken rock structure and pressure faces; few very fine and fine vesicular pores; practically no roots; few fine variegated sands; moderately alkaline (field pH 8.0); abrupt and smooth boundary to Crng1.
Crng1	156-182	Light gray (10YR 7/1), many coarse distinct dark yellowish brown (10YR 4/6) and few medium distinct yellowish brown (10YR 5/8) mottles; clay; massively bedded rock structure; moderately sticky and moderately plastic, very firm moist, hard dry; few clear clay coats along thin beds of rock structure, few fine cracks; very few fine vesicular pores; practically no roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Crng2.
Crng2	182-203+	Light gray (10YR 7/1), many coarse distinct dark yellowish brown (10YR 4/6) mottles; clay loam; massively bedded rock structure; moderately sticky and moderately plastic, very firm moist, hard dry; few faint clay coats along beds of rock structure; very few very fine vesicular pores; no roots; moderately alkaline (field pH 8.0).

Pedon 11

I Information on the site

Profile symbol	: Pedon 11
Soil name	: Phimai series
Classification	: Typic Natraqualf; Fine, kaolinitic, isohyperthermic
Date of examination	: May 18, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsoot and Saranya Norkaew
Location	: Approximately 90 m South of Talad Kae-Phimai Road (No. 2163) at ≅ 3.90 km from Talad Kae Crossroads, Ban Tum yae, Tambon Krabaung Yai, Amphoe Phimai, Nakhon Ratchasima province
Elevation	: Approximately 153 m (MSL)
Map sheet number	: 5439 Coordination : 48 0226080 m E., 1686173 m N.
Landform	
1. Physiographic position	: Flood plain
2. Surrounding landform	: Flat (nearly flat)
3. Slope on which profile site:	1%
Land use	: Paddy field, left idle at time sampling
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural and salt mining

II General information on the soil

Parent material	: Alluvium over residuum derived from fine grained sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow

Depth of ground water : Approximately 130 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng1	0-10	Mixed dark brown (7.5YR 3/3) 93% and brown (7.5YR 5/4) 5%, common fine prominent weak red (10R 4/4) mottles; clay; strong fine and medium subangular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; very few fine variegated sands, few fine cracks; few very fine and fine vesicular pores; very few very fine and fine roots; few traces of dead roots; strongly acid (field pH 5.5); abrupt and smooth boundary to Apng2.
Apng2	10-20	Mixed brown (10YR 4/3) 68% and dark yellowish brown (10YR 4/6) 30%, common fine prominent red (2.5YR 4/8) mottles; clay; strong fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on ped faces and few faint pressure faces; few fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Btng1.
Btng1	20-33	Mixed grayish brown (10YR 5/2) 63%, dark gray (10YR 4/1) 20% and light yellowish brown (10YR 6/4) 10%, common medium distinct yellowish brown (10YR 5/8) and common fine prominent yellowish red (5YR 5/8) mottles; clay; moderate fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on pore walls and few faint pressure faces; few fine cracks; very few very fine and fine vesicular and few fine simple tubular pores; practically no roots; neutral (field pH 7.0); clear and smooth boundary to Btng2.
Btng2	33-48	Mixed dark gray (10YR 4/1) 63% and dark grayish brown (2.5Y 4/2) 30%, common medium distinct olive brown (2.5Y 4/4) and common fine distinct dark yellowish brown (10YR 4/6) mottles; silty clay; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common faint clay coats on pore walls and common pressure faces; common fine cracks; very few very fine and fine vesicular and few fine dendritic tubular pores; practically no roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng3.
Btng3	48-70	Gray (10YR 6/1), common very fine distinct yellowish brown (10YR 5/8) mottles; silty clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common faint clay coats on pore walls and common pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng4.
Btng4	70-88	Light gray (10YR 7/1), common fine distinct brownish yellow (10YR 6/8) mottles; fine sandy clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common faint clay coats on pore walls and common pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; practically no roots; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng5.
2Btng5	88-114	Light gray (10YR 7/1), common medium distinct brownish yellow (10YR 6/8) and common fine distinct yellow (10YR 7/8) mottles; fine sandy clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and common faint clay bridges among sand grains; few fine cracks; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; few fine silt pockets; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng6.

2Btng6	114-135	Mixed light gray (10YR 7/2) 60% and gray (10YR 6/1) 30%, common medium distinct brownish yellow (10YR 6/8), common fine distinct yellowish brown (10YR 5/8) and common fine distinct dark gray (10YR 4/1) mottles; fine sandy clay loam; weak medium and coarse subangular blocky and semi-massive structure; slightly sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and common faint clay bridges among sand grains; very few fine cracks; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; few fine silt pockets; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng7.
2Btng7	135-156	Mixed light gray (10YR 7/2) 30% and very pale brown (10YR 7/3) 30%, many medium and coarse distinct brownish yellow (10YR 6/8) and common fine distinct yellowish brown (10YR 5/8) mottles; fine sandy loam; moderate fine and medium angular blocky structure; slightly sticky and slightly plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls and few faint clay bridges among sand grains; few traces of dead roots; few very fine and fine vesicular and few fine simple tubular pores; few fine silt pockets; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng8.
2Btng8	156-190+	Pale brown (10YR 6/3), many medium and coarse distinct yellowish brown (10YR 5/6), common fine prominent strong brown (7.5YR 4/6) and common fine distinct dark gray (10YR 4/1) mottles; fine sandy clay loam; moderate fine and medium angular blocky structure; slightly sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls and few faint clay bridges among sand grains; few traces of dead roots; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; moderately alkaline (field pH 8.0).

Pedon 12

I Information on the site

Profile symbol	: Pedon 12
Soil name	: Phimai series
Classification	: Typic Natraqualf; Very fine, kaolinitic, isohyperthermic
Date of examination	: May 18, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsoot and Saranya Norkaew
Location	: Approximately 140 m South of Talad Kae-Phimai Road (No. 2163) at $\approx$ 3.95 km from Talad Kae Crossroads, Ban Tum yae, Tambon Krabuang Yai, Amphoe Phimai, Nakhon Ratchasima province
Elevation	: Approximately 151 m (MSL)
Map sheet number	: 5439 Coordination : 48 0226128 m E., 1686136 m N.
Landform	
1. Physiographic position	: Flood plain
2. Surrounding landform	: Flat or almost flat
3. Slope on which profile site	: <2%
Land use	: Paddy field, left idle at time sampling
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural and salt mining

II General information on the soil

Parent material	: Alluvium over residuum derived from fine grained sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 140 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng1	0-18	Dark brown (7.5YR 3/2), common fine and medium prominent yellowish red (5YR 4/6) mottles; clay; strong coarse angular blocky with surface cracks structure; very sticky and very plastic, very firm moist, very hard dry; few fine cracks and common surface cracks; few very fine and fine vesicular pores; common very fine and fine and few medium roots; common traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Apng2.
Apng2	18-30	Dark gray (10YR 4/1), common fine prominent yellowish red (5YR 4/6) mottles; clay; strong fine and medium semi-angular blocky structure; very sticky and very plastic, very firm moist, hard dry; common faint clay coats on pore walls and common faint pressure faces; very few very fine and few fine vesicular and few fine dendritic tubular pores; few very fine and fine roots; common traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Btg.
Btg	42/53	Brown (10YR 5/3), common fine prominent yellowish red (5YR 4/6) mottles; clay; moderate fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on pore walls and common faint pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; few very fine and fine roots; common traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Btng1.
Btng1	42/53-64	Dark gray (10YR 4/1), common very fine prominent strong brown (7.5YR 5/6) mottles; clay; moderate fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on pore walls and common faint pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; common traces of dead roots; neutral (field pH 7.0); clear and wavy boundary to Btng2.
Btng2	64-79	Mixed gray (10YR 5/1) 63% and light brownish gray (10YR 6/2) 30%, common fine and medium distinct brown (7.5YR 5/4) and common fine prominent yellowish red (5YR 4/6) mottles; clay; moderate fine and medium angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; common distinct clay coats on ped faces and pore walls, common faint pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; neutral (field pH 7.0); clear and wavy boundary to Btng3.
Btng3	79-100	Mixed light brownish gray (10YR 6/2) 50% and gray (10YR 5/1) 48%, common fine distinct yellowish brown (10YR 5/4) mottles; clay; moderate fine and medium subangular blocky structure; moderately sticky and very plastic, firm moist, hard dry; common distinct clay coats on ped faces and pore walls, common faint pressure faces; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and wavy boundary to Btng4.
Btng4	100-124	Mixed gray (10YR 5/1) 50% and grayish brown (10YR 5/2) 45%, common medium distinct yellowish brown (10YR 5/6) mottles; silty clay; moderate fine and medium subangular blocky structure; moderately sticky and very plastic, firm

		moist, hard dry; common distinct clay coats on ped faces and pore walls, common faint pressure faces; common fine cracks; few very fine and common fine vesicular and few fine dendritic tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and wavy boundary to Btng5.
Btng5	124-151	Gray (10YR 6/1), common fine and medium yellowish brown (10YR 5/8) mottles; silty clay; weak medium and coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common faint clay coats on ped faces and pore walls; few very fine and common fine vesicular and few fine dendritic tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and wavy boundary to 2Btng6.
2Btng6	151-176	Mixed gray (10YR 6/1) 40% and light gray (10YR 7/2) 35%, common medium and coarse distinct yellowish brown (10YR 5/8) and common fine distinct dark gray (2.5Y 4/1) mottles; silty clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls; few fine cracks; few very fine and common fine vesicular and few fine simple tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng7.
2Btng7	176-200+	Mixed gray (10YR 6/1) 40% and light gray (10YR 7/2) 28%, many medium and coarse distinct yellowish brown (10YR 5/8) and common fine distinct dark gray (2.5Y 4/1) mottles; fine sandy clay; weak medium and coarse angular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on pore walls and common faint clay bridges among sand grains; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0).

Pedon 13

I Information on the site

Profile symbol	: Pedon 13
Soil name	: Phimai series
Classification	: Typic Natraqualf; Fine, kaolinitic, isohyperthermic
Date of examination	: May 19, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsoot and Saranya Norkaew
Location	: Approximately 190 m South of Talad Kae-Phimai Road (No. 2163) at $\cong$ 4.00 km from Talad Kae Crossroads, Ban Tum yae, Tambon Krabuang Yai, Amphoe Phimai, Nakhon Ratchasima province
Elevation	: Approximately 151 m (MSL)
Map sheet number	: 5439 Coordination : 48 0226176 m E., 1686103 m N.
Landform	
1. Physiographic position	: Flood plain
2. Surrounding landform	: Flat or almost flat
3. Slope on which profile site	: <2%
Land use	: Paddy rice ploughed at time sampling, <i>Eucalyptus</i> sp.
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural and salt mining

II General information on the soil

Parent material	: Alluvium over residuum derived from fine grained sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 145 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg	0-11	Brown (7.5YR 4/2), common fine and medium distinct strong brown (7.5YR 4/6) mottles; clay; weak medium and coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, very firm moist, very hard dry; common cracks (vertical); few very fine and fine vesicular and few fine dendritic tubular pores; many very fine and fine and common medium roots; common traces of dead roots; moderately acid (field pH 6.0); abrupt and smooth boundary to Btg1.
Btg1	11-32	Brown (10YR 5/3), common fine distinct yellowish brown (10YR 5/6) and common fine prominent strong brown (7.5YR 5/8) mottles; clay; moderate medium and coarse semi-angular blocky partially parting to moderate medium granulas structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls, few faint pressure face; few fine cracks; common very fine and fine vesicular and few fine dendritic tubular pores; common very fine and fine roots; many traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Btg2.
Btg2	32-56	Dark grayish brown (2.5Y 4/2), common fine and medium distinct light olive brown (2.5Y 5/6) mottles; clay; moderate medium and coarse semi-angular blocky partially parting to moderate medium granulas structure; very sticky and very plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls, few faint pressure faces; common fine cracks; common very fine and few fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; neutral (field pH 7.0); clear and smooth boundary to Btng1.
Btng1	56-65/85	Mixed light olive brown (2.5Y 5/3) 68% and light yellowish brown (2.5Y 6/3) 30%, moderate fine faint light yellowish brown (2.5Y 6/4) mottles; silty clay; moderate medium and coarse semi-angular blocky partially parting to moderate medium granulas structure; very sticky and very plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls and few faint pressure faces; common fine cracks, large slickensides across half of the horizon; common very fine, few fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and wavy boundary to Btng2.
Btng2	85-110	Gray (10YR 6/1), common medium prominent light yellowish brown (2.5Y 6/4) mottles; clay; moderate fine and medium angular blocky structure; very sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and few faint pressure faces; common fine cracks, large slickensides across half of the horizon; few very fine and fine vesicular and few fine dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng3.
Btng3	110-124	Mixed gray (2.5Y 5/1) 65% and light brownish gray (2.5Y 6/2) 30%, common medium distinct olive yellow (2.5Y 6/6) mottles; silty clay; moderate medium and coarse angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and few

		faint pressure faces; common fine cracks, large slickensides across half of the horizon; few very fine and fine vesicular and few fine dendritic tubular pores; practically no roots; moderately alkaline (field pH 8.0); abrupt and smooth boundary to 2Btng4.
2Btng4	124-152	Light gray (2.5Y 7/1), many medium and coarse distinct olive yellow (2.5Y 6/6) and few very fine prominent yellowish red (5YR 4/6) mottles; clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and common faint pressure faces; common fine cracks, large slickensides across half of the horizon; few very fine and very few fine vesicular pores; practically no roots; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng5.
2Btng5	152-180+	Light gray (2.5Y 7/1), many medium and coarse prominent olive yellow (2.5Y 6/6) and few fine prominent yellowish red (5YR 4/6) mottles; clay; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and common faint pressure faces; common fine cracks, large slickensides across half of the horizon; few very fine and very few fine vesicular pores; practically no roots; moderately alkaline (field pH 8.0).

Pedon 14

I Information on the site

Profile symbol	: Pedon 14
Soil name	: Phimai series
Classification	: Typic Endoaqualf; Fine, kaolinitic, isohyperthermic
Date of examination	: May 19, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsot and Saranya Norkaew
Location	: Approximately 240 m South of Talad Kae-Phimai Road (No. 2163) at $\cong$ 4.05 km from Talad Kae Crossroads, Ban Tum yae, Tambon Krabuang Yai, Amphoe Phimai, Nakhon Ratchasima province
Elevation	: Approximately 151 m (MSL)
Map sheet number	: 5439 Coordination : 48 0226230 m E., 1686066 m N.
Landform	
1. Physiographic position	: Flood plain
2. Surrounding landform	: Flat or almost flat
3. Slope on which profile site:	<2%
Land use	: Paddy field, ploughed at time sampling, <i>Eucalyptus sp.</i>
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural and salt mining

II General information on the soil

Parent material	: Alluvium over residuum derived from fine grained sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 110 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg1	0-10	Brown (10 YR 4/3), common fine and medium prominent red (2.5YR 4/8) mottles; clay loam; moderate medium and coarse subangular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common very fine, few fine and medium vesicular pores; common very fine, fine and medium roots; few traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Apg2.
Apg2	10-22	Dark grayish brown (10YR 4/2), common fine and medium distinct strong brown (7.5YR 5/8) and common fine prominent yellowish red (5YR 4/6) mottles; clay; strong medium and coarse angular blocky structure; moderately sticky moderately plastic, firm moist, hard dry; few faint clay coats on pore walls; few faint pressure faces; few very fine, fine and medium vesicular and few fine dendritic tubular pores; few very fine and fine roots; few traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Btg1.
Btg1	22-38	Mixed brown (7.5YR 4/3) 45%, dark grayish brown (10YR 4/2) 30% and light brown (7.5YR 6/3) 10%, common fine distinct yellowish brown (10YR 5/8) mottles; clay; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls; common variegated sands, few fine cracks; few very fine and common fine vesicular and few fine dendritic tubular pores; few very fine and fine roots; common traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Btg2.
Btg2	38-60	Mixed brown (10YR 5/3) 65% and gray (10YR 5/1) 30%, common fine distinct dark yellowish brown (10YR 4/6) mottles; clay; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; common faint clay coats on ped faces and pore walls, common faint pressure faces few fine cracks; common very fine, fine and medium vesicular pores; very few very fine and fine roots; common traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Btg3.
Btg3	60-83	Gray (10YR 6/1), common fine distinct yellow (10YR 7/8) and common very fine prominent yellowish red (5YR 5/8) mottles; silty clay; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; common faint clay coats on ped faces and pore walls, common faint pressure faces, common fine cracks; few very fine and fine vesicular pores; very few very fine and fine roots; common traces of dead roots; neutral (field pH 7.0); clear and smooth boundary to Btg4.
Btg4	83-102	Mixed light yellowish brown (2.5Y 6/3) 65% and brown (7.5YR 4/2) 10%, common medium and coarse distinct yellow (2.5Y 7/6) and common fine distinct olive yellow (2.5Y 6/8) mottles; clay; moderate medium and coarse angular blocky structure; moderately sticky and moderately plastic, very firm moist, hard dry; common faint clay coats on ped faces and pore walls, common faint pressure faces, common fine cracks; few very fine, common fine vesicular and few fine simple and dendritic tubular pores; very few very fine and fine roots; few traces of dead roots; moderately alkaline (field pH 8.0); abrupt and smooth boundary to 2Btg5.
2Btg5	102-121	Light brownish gray (2.5Y 6/2), many medium and coarse prominent olive yellow (2.5Y 6/8) and common fine prominent strong brown (7.5YR 4/6) mottles; fine sandy clay; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls, few faint pressure faces, common fine cracks; few very fine, common fine vesicular and few fine simple and dendritic tubular pores; practically no roots; few iron and aluminum oxide concretion, common traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btg6.

2Btg6	121-140	Light gray (2.5Y 7/1), many medium and coarse prominent yellowish brown (10YR 5/6) and common medium distinct brownish yellow (10YR 6/8) mottles; fine sandy clay loam; moderate fine and medium angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and common faint clay bridges among sand grains; few fine cracks; few very fine and common fine vesicular and few fine simple and dendritic tubular pores; practically no roots; few iron and aluminum oxide concretion, common traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btg7.
2Btg7	140-162	Mixed gray (10YR 6/1) 15% and light gray (10YR 7/2) 10%, many coarse prominent brownish yellow (10YR 6/8), common fine and medium distinct dark yellowish brown (10YR 4/6) and common fine prominent dark gray (10YR 4/1) mottles; fine sandy clay loam; moderate medium and coarse angular blocky structure; moderately sticky and slightly plastic, firm moist, hard dry; few faint clay coats on pore walls and common faint clay bridges among sand grains; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; few traces of dead roots and manganese oxide soft accumulation; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btg8.
2Btg8	162-190+	Mixed Pale yellow (2.5Y 7/4) 20% and very pale brown (10YR 7/3) 5%, many fine and medium prominent dark yellowish brown (10YR 4/6), common medium and coarse prominent yellowish brown (10YR 5/8) and common fine prominent dark gray (10YR 4/1) mottles; fine sandy clay loam; moderate medium and coarse angular blocky structure; slightly sticky and slightly plastic, slightly firm moist, slightly hard dry; few faint clay coats on pore walls and common faint clay bridges among sand grains; few very fine and fine vesicular and few fine simple tubular pores; practically no roots; few traces of dead roots and manganese oxide soft accumulation; moderately alkaline (field pH 8.0).

Pedon 15

I Information on the site

Profile symbol	: Pedon 15
Soil name	: Phimai series
Classification	: Typic Natraqualf; Fine, kaolinitic, isohyperthemic
Date of examination	: May 19, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Nuttaphorn Prakongkep, Chutharmard Kaewmano, Krichsana Ramsoot and Saranya Norkaew
Location	: Approximately 280 m South of Talad Kae-Phimai Road (No. 2163) at $\approx$ 4.10 km from Talad Kae Crossroads, Ban Tum yae, Tambon Krabuang Yai, Amphoe Phimai, Nakhon Ratchasima province
Elevation	: Approximately 152 m (MSL)
Map sheet number	: 5439 Coordination : 48 0226289 m E., 1686032 m N.
Landform	
1. Physiographic position	: Flood plain
2. Surrounding landform	: Flat or almost flat
3. Slope on which profile site:	<2%
Land use	: Paddy field, ploughed at time sampling, <i>Eucalyptus sp.</i>
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 27 °C
Climate	: Tropical savanna
Others	: Agricultural and salt mining

II General information on the soil

Parent material	: Alluvium over residuum derived from fine grained sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 210 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg	0-16	Brown (10YR 5/3), common fine prominent yellowish red (5YR 5/6) mottles; clay; moderate fine and medium subangular blocky structure; moderately sticky and moderately plastic, firm moist, slightly hard dry; few faint clay coats on pore walls; common surface cracks; common very fine and fine vesicular pores; many very fine, fine and medium roots; common traces of dead roots; strongly acid (field pH 5.5); abrupt and smooth boundary to Btg1.
Btg1	16-31	Dark grayish brown (10YR 4/2), common fine prominent yellowish red (5YR 4/6) mottles; clay; moderate fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on pore walls; common fine cracks; common very fine and fine vesicular and few fine simple tubular pores; few very fine and fine roots; few traces of dead roots; very strongly acid (field pH 5.0); clear and smooth boundary to Btg2.
Btg2	31-52	Grayish brown (10YR 5/2), common fine prominent yellowish red (5YR 4/6) and common fine prominent pinkish gray (7.5YR 6/2) mottles; clay; moderate fine and medium semi-angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls; few fine cracks; common very fine and fine vesicular and few fine simple and dendritic tubular pores; few very fine and fine roots; common traces of dead roots; very strongly acid (field pH 5.0); clear and smooth boundary to Btg3.
Btg3	52-69	Grayish brown (10YR 5/2), common fine prominent red (2.5YR 5/8), common fine prominent reddish yellow (7.5 YR 6/8) and few fine and medium prominent yellowish red (5YR 5/6) mottles; clay; moderate medium and coarse angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls; few fine cracks; common very fine and fine vesicular and few fine simple and dendritic tubular pores; few very fine and fine roots; few traces of dead roots; strongly acid (field pH 5.5); clear and smooth boundary to Btg4.
Btg4	69-95	Mixed dark grayish brown (10YR 4/2) 68% and grayish brown (10YR 5/2) 30%, common fine prominent strong brown (7.5YR 5/8) mottles; clay; strong medium and coarse angular blocky structure; very sticky and very plastic, very firm moist, very hard dry; common faint clay coats on ped faces and pore walls, few faint pressure faces, few fine cracks; few very fine and fine vesicular and fine dendritic tubular pores; few very fine and fine roots; slightly acid (field pH 6.5); clear and smooth boundary to 2Btng1.
2Btng1	95-128	Grayish Brown (2.5Y 5/2), common fine and medium distinct olive yellow (2.5Y 6/6); clay; moderate fine and medium semi-angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls, few faint pressure faces, few fine cracks; very few very fine and few fine vesicular pores; practically no roots; few traces of dead roots; neutral (field pH 7.0); clear and smooth boundary to 2Btng2.
2Btng2	128-161	Mixed light brownish gray (2.5Y 6/2) 70% and light yellowish brown (2.5Y 6/4) 10%, common medium distinct olive yellow (2.5Y 6/6) mottles; clay; weak coarse angular blocky and semi-massive structure; slightly sticky and moderately plastic, firm moist, hard dry; common distinct clay coats on ped faces and pore

		walls; common fine cracks; few very fine and fine vesicular and fine dendritic tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng3.
2Btng3	161-187	Mixed light gray (2.5Y 7/1) 30% and light yellowish brown (2.5Y 6/4) 30%, many fine and medium prominent brownish yellow (10YR 6/8) mottles; clay; moderate medium and coarse semi-angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; common distinct clay coats on ped faces and pore walls; common cracks of various sizes; few very fine and fine vesicular and fine dendritic tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); gradual and smooth boundary to 2Btng4.
2Btng4	187-210+	Mixed pale brown (2.5Y 7/4) 30% and light gray (2.5Y 7/1) 15%, many coarse and medium prominent olive yellow (2.5Y 6/8) and common coarse and medium prominent brownish yellow (10YR 6/8) mottles; clay; weak coarse angular blocky and semi-massive structure; slightly sticky and moderately plastic, firm moist, hard dry; few distinct clay coats on ped faces and pore walls; common fine cracks; few very fine and fine vesicular and few fine dendritic tubular pores; practically no roots; strongly alkaline (field pH 8.5).

Pedon 16

I Information on the site

Profile symbol	: Pedon 16
Soil name	: Roi Et saline variant
Classification	: Aeris Kandiaqualf; Fine-loamy, siliceous, isohyperthermic
Date of examination	: May 16, 1992
Described by	: Irb Kheoruenromne, Anchalee Suddhiprakarn, Somchai Anusontpornperm, Kanitasri Songsawasdi and others
Location	: Approximately 50 m west of Mitraparp Rd. opposite to Ban Kroke Samrong school, approximately 8 km Ban Wat, Ban Kroke, Tambon Non Ta Thel, King Amphoe Non Daeng, Nakhon Ratchasima province
Elevation	: Approximately 160 m (MSL)
Landform	
1. Physiographic position	: Middle part of low terrace
2. Surrounding landform	: gently undulating
3. Slope on which profile site:	2%
Land use	: paddy rice (15 buckets/rai)
Annual rainfall	: approximately 1,100 mm
Mean temperature	: approximately 26°C
Climate	: Tropical savanna
Others	: bamboo, pine, <i>Eucalyptus</i> sp.

II General information on the soil

Parent material	: Local alluvium derived from calcareous rocks
Drainage	: Somewhat poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg	0-18	Very dark grayish brown (10YR 3/2), few fine distinct yellowish brown (10YR 5/6) mottles; sandy loam; strong medium and coarse angular blocky structure; hard dry, friable moist, slightly sticky and slightly plastic; common very fine and fine vesicular and fine tubular pores; many very fine and fine roots; presence of few variegated sands; moderately alkaline (field pH 8.0); abrupt, smooth boundary to Btg1.
Btg1	18-36	Dark brown (7.5YR 4/2) few fine prominent yellowish brown (10YR 5/6) mottles; sandy loam; strong coarse prismatic parting to medium and coarse angular blocky structure; very hard dry, friable moist, slightly sticky and slightly plastic; few thin patchy clay coats mainly on pore walls; few very fine and common fine vesicular and few fine tubular pores; common very fine and fine roots; trace of dead roots; moderately alkaline (field pH 8.0); clear, smooth boundary to Btg2.
Btg2	36-63	Mixed brown (7.5YR 5/2) 90% and light brown (7.5YR 6/4) 10%, few fine prominent yellowish brown (10YR 5/6) and few fine prominent black (7.5YR 2/0) mottles; sandy clay loam; strong large prismatic parting to medium and coarse angular blocky structure; very hard dry, friable moist, slightly sticky and slightly plastic; thin patchy clay coats mainly on pore walls; few very fine and common fine vesicular and few fine tubular pores; common very fine and fine roots; few manganese oxide nodules; moderately alkaline (field pH 8.0); gradual, smooth boundary to Btg3.
Btg3	63-101	Mixed pinkish gray (7.5YR 6/2) 90% and light brown (7.5YR 6/4) 10%, few fine prominent yellowish brown (10YR 5/6) mottles; sandy loam; strong large prismatic parting to medium and coarse angular blocky structure; firm moist, slightly sticky and slightly plastic; patchy clay coats on pore walls and clay bridges between sand grain; few very fine and fine vesicular and tubular pores; few very fine and fine roots; common black (7.5YR 2/0) manganese oxide nodules and few lime nodules; moderately alkaline (field pH 8.0); clear, smooth boundary to Btkg.
Btkg	101-123	Light yellowish brown (10YR 6/4) few fine faint yellowish brown (10YR 5/6) and few fine prominent (5YR 5/6) mottles; sandy clay loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; few thin patchy clay coats on pore walls and patch of clay bridges between sand grains; few fine and medium vesicular and few fine tubular pores; few very fine and fine roots; common manganese oxide nodules and many lime nodules; moderately alkaline (field pH 8.0); abrupt, smooth boundary to BCkg.
BCkg	123-135	Light yellowish brown (10YR 6/4) common fine distinct yellow (10YR 7/8) and few fine prominent red (2.5YR 5/6) mottles; gravelly clay loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; some clay bridges; few fine and medium vesicular pores; few very fine and fine roots; abundant lime nodules; moderately alkaline (field pH 8.0); clear, smooth boundary to Ckg1.
Ckg1	135-160	Light yellowish brown (10YR 6/4) few fine distinct yellow (10YR 7/8) and few fine prominent red (2.5YR 5/8) mottles; slightly gravelly sandy clay; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; some clay bridges; few fine and medium vesicular pores; very few very fine and fine roots; practically a marl layer with lime nodules; moderately alkaline (field pH 8.0); gradual, smooth boundary to Ckg2.
Ckg2	160-195+	Light gray (2.5YR 7/2) few fine prominent yellow (10YR 7/8) mottles; gravelly clay; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; few fine and medium vesicular pores; very few very fine and fine roots; practically a marl layer with lime nodules; moderately alkaline (field pH 8.0).

Pedon 17**I Information on the site**

Profile symbol	: Pedon 17
Soil name	: Roi Et, saline variant
Classification	: Typic Natraqualf; Sandy, silicious, isohyperthermic
Date of examination	: 24 December 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Punyisa Trakoonyingcharoen, Suphicha Thanachit, Nuttaphorn Prakongkep, Krichsana Ramsoot, Saranya Norkaew and Ladawan Nakforn
Location	: Approximately 100 m West of Sida-bua Yai Road (No. 202) at 7.0 km from Sida Crossroads, Ban Nong Klang Yai, Tambon Kut Chok, Amphoe Bua Yai, Nakhon Ratchasima province
Elevation	: Approximately 160 m (MSL)
Map sheet number	: 5440 II Coordination : 48 0229582 m E., 1721187 m N.
Landform	
1. Physiographic position	: Erosional plain
2. Surrounding landform	: Gently undulating
3. Slope on which profile site:	2%
Land use	: Paddy field, left idle at time of sampling under local weeds, salt tolerant species
Annual rainfall	: Approximately 1,100 mm
Mean temperature	: Approximately 26 °C
Climate	: Tropical savanna
Others	: Garbage disposal pond

II General information on the soil

Parent material	: Wash over residuum derived from weathered clastic sedimentary rocks
Drainage	: Poorly drained
Permeability	: Moderate
Runoff	: Slow
Depth of ground water	: Approximately 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-11	Mixed pink (7.5YR 7/3) 70% and yellowish red (5YR 5/8) 13%, common medium prominent strong brown (7.5YR 5/8), common medium distinct brown (7.5YR 4/2) and common fine distinct dark brown (7.5YR 3/2) mottles; loamy sand; moderate weak fine and medium subangular blocky structure; slightly sticky and non plastic, friable moist, soft dry; common variegated sands; common very fine and fine vesicular pores; common very fine and fine roots; common traces of dead roots; neutral (field pH 7.0); clear and smooth boundary to Bng1.
Bng1	11-30	Mixed pinkish gray (7.5YR 7/2) 70% and reddish yellow (5YR 6/6) 12%, common fine prominent strong brown (7.5YR 5/8) and black (7.5YR 2.5/1) and common fine distinct strong brown (7.5YR 5/6) mottles; loamy sand; weak fine and medium subangular blocky structure; non-sticky and non-plastic, friable moist, loose dry; common variegated sands; common very fine and fine vesicular pores; few very fine and fine roots; common traces of dead roots; strongly alkaline (field pH 8.5); clear and smooth boundary to Bng2.
Bng2	30-47	Mixed pinkish gray (7.5YR 7/2) 80% and reddish yellow (5YR 6/8) 15%, common fine prominent yellow (10YR 7/8) mottles; loamy sand; moderate weak fine and medium semi-angular blocky structure; non-sticky and non-plastic, friable moist, soft dry; common variegated sands; common very fine and fine

		vesicular pores; very few very fine and medium roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng1.
Btng1	47-69/76	Mixed pinkish gray (7.5YR 7/2) 70% and yellowish red (5YR 5/8) 20%, common fine prominent brownish yellow (10YR 6/8) mottles; sandy loam; moderate weak fine and medium semi-angular blocky structure; slightly sticky and non-plastic, friable moist, slightly hard dry; few faint clay bridges among sand grains; common variegated sands; few very fine and fine and medium vesicular pores; very few very fine and fine roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng2.
Btng2	76-95	Mixed pink (7.5YR 7/3) 60%, light gray (10YR 7/2) 20% and yellowish red sand grain (5YR 5/8) 10%, common fine prominent yellowish red (5YR 5/8), yellow (10YR 7/8) and very dark grayish brown (10YR 3/2) mottles; sandy loam; moderate fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, slightly firm moist, slightly hard dry; common faint clay bridges among sand grains; common variegated sands, few iron-manganese oxide nodules; very few very fine, few fine and medium vesicular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and smooth boundary to Btng3.
Btng3	95-110	Mixed pink (7.5YR 7/3) 60%, light gray (10YR 7/2) 20% and yellowish red sand grain (5YR 5/8) 10%, common medium prominent brownish yellow (10YR 6/8), common fine prominent yellowish red (5YR 5/8) and dark yellowish brown (10YR 3/4) mottles; sandy loam; moderate medium and coarse semi-angular blocky structure; slightly sticky and slightly plastic, slightly firm moist, slightly hard dry; very few faint clay coats on ped faces and common faint clay bridges among sand grains; common variegated sands, few iron-manganese oxide nodules; very few very fine, few fine and medium vesicular pores; practically no roots; few traces of dead roots; strongly alkaline (field pH 8.5); clear and smooth boundary to Btng4.
Btng4	110-131	Mixed pink (7.5YR 7/3) 50%, light gray (10YR 7/1) 15% and yellowish red (5YR 5/8) 15%, common medium prominent reddish yellow (7.5YR 6/8) and common fine prominent yellow (10YR 8/8) and dark yellowish brown manganese oxide nodule (10YR 3/4) mottles; sandy loam; moderate medium and coarse semi-angular blocky structure; slightly sticky and slightly plastic, firm moist, slightly hard dry; very few faint clay coats on pore walls and common faint clay bridges among sand grains; common variegated sands, few iron-manganese oxide nodules; few very fine and fine and very few medium vesicular pores; practically no roots; few traces of dead roots; strongly alkaline (field pH 8.5); clear and smooth boundary to Btng5.
Btng5	131-153	Mixed light red (2.5YR 6/6) 50%, pinkish gray (5YR 7/2) 20% and reddish yellow sand grain (5YR 6/8) 10%, common medium prominent reddish yellow (5YR 6/8) and yellow (10YR 7/6) and common fine prominent black manganese oxide nodule (10YR 2/1) mottles; sandy loam; moderate medium and coarse semi-angular blocky structure; moderately sticky and slightly plastic, firm moist, slightly hard dry; very few faint clay coats on pore walls and common faint clay bridges among sand grains; common variegated sands, very few iron-manganese oxide nodules; very few very fine and few fine vesicular pores; practically no roots; strongly alkaline (field pH 8.5); abrupt and smooth boundary to 2Btng6.
2Btng6	153-178	Mixed pink (7.5YR 7/3) 60%, light gray (10YR 7/1) 10%, yellowish red (5YR 5/6) 10% and light gray (10YR 7/2) 5%, common coarse prominent brownish yellow (10YR 6/8), common fine distinct strong brown (7.5YR 5/6) and common medium prominent black manganese oxide nodule (7.5YR 2.5/1) mottles; sandy clay loam; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, very firm moist, hard dry; common faint clay coats on ped faces and pore walls and common faint clay bridges among sand grains; common variegated sands, some translocated sand patches; few very fine and fine

		and medium vesicular pores; practically no roots; few large manganese oxide nodules, few clay blocks; strongly alkaline (field pH 8.5); clear and smooth boundary to 2Btng7.
2Btng7	178-200+	Mixed light red (2.5YR 7/6) 40%, reddish brown (2.5YR 4/4) 20%, light gray (10YR 7/1) 10% and (5YR 7/1) 10%, common medium prominent reddish yellow (7.5YR 6/8), yellow (10YR 8/8) and black manganese oxide nodule (7.5YR 2.5/1) mottles; sandy clay loam; weak coarse angular blocky and semi-massive structure; moderately sticky and moderately plastic, firm moist, hard dry; common faint clay coats on ped faces and pore walls and common faint clay bridges among sand grains; common variegated sands, some translocated sand patches; few very fine, common fine and few medium vesicular and few fine tubular pores; practically no roots; strongly alkaline (field pH 8.5).

Pedon 18

I Information on the site

Profile symbol	: Pedon 18
Soil name	: Roi-Et saline variant
Classification	: Typic Natraqualf; Fine, Kaolinitic, isohyperthermic
Date of examination	: April 10, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 180 m west of Phuthaisong Buriram road at km 1 from Phutthaisong, Ban Huai Toei, Amphoe Phutthaisong Buriram Province.
Elevation	: Approximately 144 m (MSL)
Landform	
1. Physiographic position	: Depression on low alluvial terrace
2. Surrounding landform	: Slightly undulating
3. Slope on which profile site:	2%
Land use	: Transplanted rice
Annual rainfall	: Approximately 1,200 mm
Mean temperature	: Approximately 26.7 °C
Climate	: Tropical savanna

II General information on the soil

Parent material	: Mixed alluvium local and riverine
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: Approximately 180 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-20/23	Weak red (7.5YR 5/2) 80% and common prominent red (2.5YR 5/8) 20% mottles; loam; moderate fine and medium subangular blocky structure; slightly hard dry, firm moist, slightly sticky and slightly plastic; common very fine vesicular and few simple tubular pores; many very fine, fine and common medium roots; slightly acid (field pH 6.5); abrupt, smooth boundary to Btng1.

Btng1	20/23-35/42	Weak red (5YR 4/2) 90% and common distinct red (2.5YR 4/8) 10% mottles; silty clay loam; moderate fine and medium subangular blocky structure and moderately fine and medium semi-prismatic structure; hard dry, firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains, very fine and fine vesicular and few fine simple tubular pores; few very fine and fine roots; very strongly acid (field pH 4.5); clear, wavy boundary to Btng2.
Btng2	35/42-62/72	Reddish brown (5YR 5/3) 65% and many distinct red (2.5YR 5/8) 35% mottles; silty clay loam; moderate fine and medium subangular blocky structure and moderately medium semi-prismatic structure; hard dry, firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and common thin patchy clay coats on tubular pore walls; common very fine and fine vesicular and few fine simple tubular pores, few very fine and fine roots; strongly acid (field pH 5.5); clear, wavy boundary to Btng3.
Btng3	62/72-118	Dark gray brown (10YR 4/2) 90% and common prominent redsish yellow (7.5YR 7/8) 10% mottles; silty clay; strong fine and medium subangular and angular blocky structure; very firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and thin patchy clay coats on pore walls; few pressure faces; few very fine and fine roots; medium acid (field pH 6.0); gradual, wavy boundary to Btng4.
Btng4	118-122/137	Dark brown (7.5YR 4/2) 92% and common prominent redsish yellow (5YR 7/8) 8% mottles; clay; strong fine and medium angular and subangular blocky structure; very firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and thin patchy clay coats on pore walls; few pressure faces; no roots; strongly acid (field pH 5.5); gradual, wavy boundary to Btng5.
Btng5	122/137-162/168	Reddish gray (5YR 5/2) 82% and common distinct reddish yellow (7.5YR 6/8) 15% mottles; clay; moderate fine and medium angular and subangular blocky structure; firm moist, slightly sticky and slightly plastic; common thin clay coats on ped faces and pore walls; few medium soft iron and manganese oxides concretions; common very fine and fine vesicular few fine simple tubular pores; no roots; strongly acid (field pH 5.5); gradual, wavy boundary to Btng6.
Btng6	162/168-193+	Very dark gray brown (10YR 3/2) 92% and common distinct yellow brown (10YR 5/8) 8% mottles; clay; moderate fine and medium angular blocky structure; firm moist, slightly sticky and slightly plastic; common thin clay coats on ped faces and pore walls; common very fine and fine vesicular few fine simple tubular pores; no roots; strongly acid (field pH 5.5).

Pedon 19

I Information on the site

Profile symbol	: Pedon 19
Soil name	: Roi Et saline variant
Classification	: Typic Natraqualf; Coarse-loamy, mixed, isohyperthermic
Date of examination	: April 1, 1990
Described by	: Irb Kheoruenromne, Jumpol Vichiansinpa and others
Location	: Approximately 150 m West of Wapi Pathum Phayakkhaphum Phisai road at Km 2 from Wapi Pathum; Ban Jok Khwang, Tambon Nong saeng, Amphoe Wapee Pathum, Maha Sarakham Province.
Elevation	: Approximately 146 m (MSL)

Landform

1. Physiographic position : Low alluvial Terrace
 2. Surrounding landform : Slightly undulating
 3. Slope on which profile site: 3%
- Land use : Paddy rice
 Annual rainfall : Approximately 1,400 mm
 Mean temperature : Approximately 27.1 °C
 Climate : Tropical savanna

II General information on the soil

- Parent material : Local alluvium and wash deposit mainly
 Drainage : Somewhat poorly drained
 Permeability : Moderate
 Runoff : Slow
 Depth of ground water : Approximately 70 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apng	0-13/16	Mixed light red brown (5YR 6/4) 85% with yellowish red (5YR 5/8) 10% and common distinct black (5 YR 2/1) 5% mottles; Loamy sand; moderately weak fine and medium subangular blocky structure; slightly hard dry, friable moist, non-sticky and non-plastic; presence of dark thin discontinuous layers; many very fine and fine vesicular and few fine simple tubular pores; many very fine and few medium roots; very strongly acid (field pH 5.0); abrupt, wavy boundary to Bng1.
Bng1	13/16-35/37	Light reddish brown (5YR 6/4) 85% and strong common distinct brown (7.5YR 5/8) 15% mottles; sandy loam; weak fine and coarse subangular blocky structure; friable moist, non-sticky and non-plastic; few thin accumulation of iron oxide on tubular pore walls; common very fine and fine vesicular and few fine simple tubular pores; common very fine and fine roots; strongly acid (field pH 5.5); clear, wavy boundary to Bng2.
Bng2	35/37-58	Reddish yellow (5YR 6/6) 90% and common distinct yellowish red (5YR 5/8) 10% mottles; sandy loam; weak fine and medium subangular blocky structure; very friable moist, non-sticky and non-plastic; trace of dead fine roots; common very fine and fine vesicular pores; very fine and fine roots; strongly acid (field pH 5.5); abrupt, smooth boundary to Btng1.
Btng1	58-86	Light reddish brown (5YR 6/4) 90% and common faint reddish yellow (5YR 6/8) 10% mottles; sandy clay loam; moderate weak fine and medium subangular blocky structure; friable moist, slightly sticky and slightly plastic; common clay bridges on sand grains and very fine thin patchy clay coats on pore walls; many very fine and common fine vesicular pores; no roots; very strongly acid (field pH 5.0); abrupt, smooth boundary to Btng2.
Btng2	86-100	Light reddish brown (5YR 6/4) 70% and many reddish yellow (5YR 6/8) 30% mottles; sandy clay loam; moderate fine and medium subangular blocky structure; friable moist, slightly sticky and slightly plastic; common clay bridges on sand grains and very few thin patchy clay coats on pore walls; common very fine and few fine simple tubular pores; no roots; medium acid (field pH 6.0); abrupt, smooth boundary to Btng3.
Btng3	100-108/120	Light reddish brown (5YR 6/3) 95% and common reddish faint yellow (5YR 6/8) 5% mottles; sandy loam; moderate fine and medium subangular blocky structure; slightly firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and very few thin patchy clay coats on tube pore wall; common very fine and few fine simple tubular pores; no roots; strongly acid (field pH 5.5); abrupt, wavy boundary to Btg4.

Btng4	120-125/131	Strong brown (7.5YR 5/8) 95% and common red prominent (2.5YR 4/8) 5% mottles; clay loam; moderate fine and medium subangular blocky structure; hard dry, firm moist, slightly sticky and slightly plastic; common clay bridges on sand grains and very fine thin patchy clay coats on tube pore walls; few very fine and fine vesicular pores; no roots; strongly acid (field pH 5.5); abrupt, wavy boundary to Cng.
Cng	131-160+	Pinkish gray (7.5YR 6/2); sandy loam; weak medium and coarse subangular blocky structure (semi-massive); slightly firm moist, slightly sticky and slightly plastic; few very cracks; few very fine and fine vesicular pores; no roots; slightly acid (field pH 6.5).

Pedon 20

I Information on the site

Profile symbol	: Pedon 20
Soil name	: Kula Ronghai series
Classification	: Typic Natraqualf; Fine, kaolinitic, isohyperthermic
Date of examination	: December 15, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Saowanuch Tawornpruek, Nuttaphorn Prakongkep, Krichsana Ramsoot, Saranya Norkaew and Supaluk Srithilertcharoen
Location	: Approximately 50 m East of Suwanaphume-Tha Tum Road (No. 214) at 9.90 km from Suwanaphume Crossroads, Ban Don Phiman, Tambon Sra Ku, Amphoe Suwanaphume, Roi-Et province
Elevation	: Approximately 116 m (MSL)
Map sheet number	: 5740 II Coordination : 48 0372031 m E., 1717235 m N.
Landform	
1. Physiographic position	: Erosional plain
2. Surrounding landform	: Flat
3. Slope on which profile site:	2%
Land use	: Paddy rice (KDML 105)/Eucalyptus
Annual rainfall	: Approximately 1,300 mm
Mean temperature	: Approximately 26 °C
Climate	: Tropical savanna
Others	: Agricultural

II General information on the soil

Parent material	: Wash over residuum derived from clastic sedimentary rock (siltstone)
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: More than 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg	0-15/23	Light brownish gray (10YR 6/2), common fine distinct yellowish brown (10YR 5/6) mottles; slightly gravelly sandy loam; moderate weak fine and medium subangular blocky structure; slightly sticky and slightly plastic, friable moist, slightly hard dry; few iron-manganese oxides nodules and concretion; few fine and medium vesicular pores; many very fine and fine roots; few traces of dead roots; strongly acid (field pH 5.5); abrupt and wavy boundary to Bcg.

Bcg	23-46	Light gray (10YR 7/1), common fine and medium distinct black (10YR 2/1) and common fine distinct brownish yellow (10YR 6/8) mottles; slightly gravelly fine sandy clay; massive structure; very sticky and very plastic, very firm moist, very hard dry; very few very fine variegated sands; very few very fine vesicular pores; few very fine and fine and medium roots; abundant iron-manganese nodules and concretion in some parts; moderately alkaline (field pH 8.0); gradual and smooth boundary to Btg1.
Btg1	46-65	Light gray (10YR 7/1), common fine and medium prominent yellow (2.5Y 7/8) mottles; fine sandy clay; weak coarse angular blocky structure (semi-massive); very sticky and very plastic, very firm moist, very hard dry; few faint clay coats on pore walls; few very fine variegated sands, few pressure faces; few fine and medium vesicular pores; very few fine and few medium roots; few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to Btg2.
Btg2	65-88	Light gray (10YR 7/2), common medium prominent yellow (2.5Y 7/8) mottles; fine sandy clay; weak coarse angular blocky structure (semi-massive); very sticky and very plastic, very firm moist, very hard dry; common faint clay coats on pore walls; few very fine variegated sands, few pressure faces; few fine and medium vesicular pores; very few fine and medium roots; few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to Btg3.
Btg3	88-113	Light gray (2.5Y 7/1), common coarse prominent brownish yellow (10YR 6/8) and common medium prominent dark red (10R 3/6) mottles; fine sandy clay; moderate fine and medium angular blocky structure; very sticky and very plastic, firm moist, very hard dry; common faint clay coats on pore walls; few very fine variegated sands, few pressure faces; few fine variegated sands; few very fine and fine vesicular and simple tubular pores; particular no roots; few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng1.
2Btng1	113-140	Light gray (10YR 7/2), many coarse distinct brownish yellow (10YR 6/8) and common medium prominent dark red (10R 3/6) mottles; sandy clay; moderate medium and coarse semi angular blocky structure; slightly sticky and moderately plastic, firm moist, hard dry; common faint clay coats on pore walls and few faint clay bridges among sand grains; few very fine, common fine vesicular and few fine tubular pores; particular no roots; few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng2.
2Btng2	140-172	Light gray (10YR 7/2), common coarse distinct brownish yellow (10YR 6/8) and common medium prominent dark red (10R 3/6) mottles; sandy clay; moderate medium and coarse semi angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and many faint clay bridges among sand grains; few very fine, common fine vesicular and few fine tubular pores; particular no roots; few fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btng3.
2Btng3	170-205+	Light gray (10YR 7/2), common coarse distinct brownish yellow (10YR 6/8) and common medium prominent dark red (10R 3/6) mottles; sandy clay; moderate fine and medium semi angular blocky structure; moderately sticky and moderately plastic, firm moist, hard dry; few faint clay coats on pore walls and many faint clay bridges among sand grains; few very fine, common fine vesicular and few fine tubular pores; particular no roots; few iron oxides slightly hard nodules; moderately alkaline (field pH 8.0).

Pedon 21**I Information on the site**

Profile symbol	: Pedon 21
Soil name	: Kula Ronghai series
Classification	: Typic Natraqualf; Fine, kaolinitic, isohyperthermic
Date of examination	: December 16, 2004
Described by	: Irb Kheoruenromne, Napaporn Wongpokhom, Somchai Anusontpornperm, Saowanuch Tawornpruek, Nuttaphorn Prakongkep, Krichsana Ramsoot, Saranya Norkaew and Supaluk Srithilertcharoen
Location	: Approximately 110 m East of Suwanaphume-Tha Tum Road (No. 214) at 9.90 km from Suwanaphume Crossroads, Ban Don Phiman, Tambon Sra Ku, Amphoe Suwanaphume, Roi-Et province
Elevation	: Approximately 117 m (MSL)
Map sheet number	: 5740 II Coordination : 48 0372074 m E., 1717206 m N.
Landform	
1. Physiographic position	: Erosional plain
2. Surrounding landform	: Flat
3. Slope on which profile site:	1%
Land use	: Paddy rice (KDML 105)/Eucalyptus
Annual rainfall	: Approximately 1,300 mm
Mean temperature	: Approximately 26 °C
Climate	: Tropical savanna
Others	: Agricultural

II General information on the soil

Parent material	: Wash over residuum derived from clastic sedimentary rock
Drainage	: Poorly drained
Permeability	: Slow
Runoff	: Slow
Depth of ground water	: More than 200 cm at time of sampling

III Profile description

Horizon	Depth (cm)	Description
Apg	0-19/20	Mixed gray (10YR 5/1) 60% and brown (7.5YR 5/3) 38%, common fine distinct brownish yellow (10YR 6/8) mottles; fine sandy loam; moderate weak fine and medium semi-angular blocky structure; slightly sticky and slightly plastic, friable moist, slightly hard dry; very fine very few variegated sands; common very fine and fine vesicular and very few fine simple tubular pores; many very fine and fine roots; few traces of dead roots; moderately acid (field pH 6.0); clear and smooth boundary to Apng.
Apng	20-27/32	Mixed pink (7.5YR 7/4) 95% and gray (7.5YR 5/1) 3%, common fine distinct reddish yellow (7.5YR 6/8) mottles; fine sandy loam (loamy fine sand); moderate weak fine and medium semi-angular blocky structure; non sticky and non plastic, vary friable moist, slightly hard dry; very fine very few variegated sands and few fine cracks; common very fine and fine vesicular and very few fine simple tubular pores; few very fine and fine roots; few iron-manganese oxides nodules and concretion; moderately acid (field pH 6.0); abrupt and wavy boundary to Bcg.
Bcg	32-54/63	Mixed light gray (10YR 7/2) 40% and (10YR 7/1) 35%, pinkish gray (7.5YR 6/2) 10% and reddish yellow shifted sands (5YR 6/6) 5%, common fine and medium distinct gray (10YR 5/1) and black manganese oxide (10YR 2/1) mottles; slightly gravelly fine sandy clay; massive structure; very sticky and very plastic, vary firm

		moist, very hard dry; few fine faint clay coat on pore walls; common vertical cracks and common iron-manganese concretions and nodules; very few very fine and fine vesicular and few fine simple vertical tubular pores; very few very fine and fine roots; common translocates fine sands in cracks and vertical tubular pores; moderately alkaline (field pH 8.0); abrupt and broken boundary to Btg1.
Btg1	63-82/87	Mixed light gray (10YR 7/2) 70% and (7.5YR 7/1) 10%, pinkish gray (7.5YR 7/2) 10% and light reddish brown shifted sands (5YR 6/4) 5%, common fine prominent light red (2.5YR 6/6) mottles; fine sandy clay; weak coarse angular blocky (semi-massive) structure; very sticky and very plastic, vary firm moist, very hard dry; common faint clay coat on pore walls; few faint pressure faces and few fine variegated sands; very few very fine and few fine vesicular and few fine simple tubular pores; practically no roots; few traces of dead roots; moderately alkaline (field pH 8.0); clear and wavy boundary to Btg2.
Btg2	87-111/114	Mixed light gray (10YR 7/2) 58% and (10YR 7/1) 20% and light reddish brown shifted sands (5YR 6/4) 2%, common medium and coarse distinct brownish yellow (10YR 6/8) and common medium distinct yellowish brown (10YR 5/8) mottles; fine sandy clay; weak coarse angular blocky (semi-massive) structure; very sticky and very plastic, vary firm moist, very hard dry; common faint clay coat on pore walls and along smooth crack surface; very few large iron oxides semi-hardened nodules; very few very fine and few fine vesicular and few fine simple tubular pores; practically no roots; common fine cracks; moderately alkaline (field pH 8.0); clear and smooth boundary to 2Btg3.
2Btg3	114-137	Mixed light gray (10YR 7/2) 63% and (10YR 7/1) 10%, common medium and coarse distinct yellowish brown (10YR 5/8), common medium prominent red (2.5YR 4/6) and common medium distinct dark gray manganese oxide (10YR 4/1) mottles; silty clay (very fine sandy clay); moderate medium and coarse semi-angular blocky structure; very sticky and very plastic, vary firm moist, very hard dry; common faint clay coat on pore walls; few iron-oxides impregnated nodules and very few fine variegated sands; very few very fine and few fine vesicular and few fine simple tubular pores; practically no roots; common fine and medium cracks; strongly alkaline (field pH 8.5); gradual and smooth boundary to 2Btg4.
2Btg4	137-155	Mixed light gray (10YR 7/2) 62% and (10YR 7/1) 5%, many medium and coarse distinct yellowish brown (10YR 5/8), common medium and coarse prominent olive yellow (2.5Y 6/6) and common fine and medium prominent red (10R 4/8) mottles; very fine sandy clay; moderate medium and coarse semi-angular blocky structure; moderately sticky and very plastic, firm moist, hard dry; common faint clay coat on pore walls; very few iron-oxides impregnated nodules; very few very fine and fine vesicular and very few fine tubular pores; practically no roots; common fine cracks; strongly alkaline (field pH 8.5); clear and smooth boundary to 2Btng1.
2Btng1	155-183	Light gray (10YR 7/2), common medium and coarse distinct yellowish brown (10YR 5/8) and brownish yellow (10YR 6/8) and common fine and medium prominent red (10R 4/8) and (10R 5/8) mottles; fine (very fine) sandy clay; moderate medium and coarse semi-angular blocky structure; moderately sticky and very plastic, firm moist, hard dry; common faint clay coat on pore walls; very few iron-oxides impregnated nodules and evidence of translocated sands along vertical crack; very few very fine and fine vesicular and very few fine tubular pores; practically no roots; common fine cracks; strongly alkaline (field pH 8.5); gradual and smooth boundary to 2Btng2.
2Btng2	183-207+	Light gray (10YR 7/2), many medium and coarse distinct yellowish brown (10YR 5/8), many medium and coarse prominent red (10R 5/8) and common medium distinct dark yellowish brown (10YR 4/8) mottles; fine sandy clay; moderate medium and coarse semi-angular blocky structure; moderately sticky and very plastic, firm moist, hard dry; common faint clay coat on pore walls; evidence of translocated sands along vertical crack; very few very fine and fine vesicular and few fine simple tubular pores; practically no roots; common fine cracks; strongly alkaline (field pH 8.5).

Appendix B

Methods of laboratory analyses

Physical Analyses

Particle Size Analysis

Particle size analysis was carried out to evaluate soil texture. A mass of 10 g air dried soil sample was pretreated to remove free soluble salt by washing in distilled water, centrifuging and decanting. For dispersion of soil, the soil was placed in a milk shake container and 10 mL of 5% sodium hexametaphosphate, a dispersing agent, was added. The volume of the contents was made up to about 200 mL with deionised water, the contents were stirred for 15 minutes on the milk shake mixer. The contents were then sieved through a 300-mesh (0.047 mm) sieve into a one litre cylinder and volume was made up to about 200 mL with deionized water. The sand grains that remained in the sieve were dried at 105°C overnight and were weighed. The suspension in the cylinder was stirred well with an agitator in an up-down motion for 30 s. The pipette method was used as a direct sampling procedure. Twenty five millilitres of suspension was pipetted from a depth of 10 cm for clay at appropriate times based on Stoke's Law (i.e. at 25°C for <0.002 mm sized fraction sampling time at 10 cm depth is 6 hr). Suspensions were dried at 105°C and weighed (Gee and Bauder, 1986). The amount of sand, silt and clay were calculated. The percentage of clay (<2 µm), silt (0.002 to 0.05 mm) and sand (0.05 to <2 mm) were plotted on ternary plots, and soils were classified using soil textural triangle classes (Soil Survey Staff, 1998).

Hydraulic Conductivity (K_{sat})

A saturated undisturbed soil (core sample) was installed in a cylinder and supplied with water to the bottom of the sample. During the water flow in the standpipe, measured the time for the water level to fall from H₁ to H₂. Calculation of the hydraulic conductivity was from the equation:

$$K_{sat} = (aL/At) \log_e (H_1/H_2)$$

where K_{sat} = hydraulic conductivity value, a = the cross sectional area of the standpipe, L = the soil sample length, A = cross section area of the sample, t = time, H_1 = height of initial water and H_2 = height of final water (Klute and Dirksen, 1986)

Bulk Density (BD)

Bulk density is the mass of dry solid per unit bulk volume of the soil. The bulk volume includes the volume of both solid and pore space. Bulk density varies with structural condition of the soil. It is often used as a measure of soil structure. The undisturbed clod sample (size of about 2-3 cm, diameter) was oven dried at 105 °C. The clod and attached thread were weighed in air and the clod was then dipped into paraffin wax. The paraffin wax-coated clod was weighed in air and in water. The difference in these weights provides the weight of water that has same volume as the volume of the paraffin wax-coated clod. The density of water and paraffin, weights of oven-dry clod, in air, clod plus paraffin coating in air and in water were used to calculate the bulk density which is reported in units of $Mg\ m^{-3}$ (Blake and Hartge, 1986).

Wet aggregate Stability Analysis

Aggregate stability was determined following the principle that unstable aggregates will break down more easily than stable aggregates when dry aggregates are immersed to water. For this study, the wet sieving method described by Kemper and Rosenau (1986) was used to determine aggregate stability. Aggregates of 1 to 2 mm size have been found by these and other workers (Seybold and Herrick 2001; Ruiz-Vera and Wu 2006) to be best suited to the screen size and sieving speed employed in this procedure.

Four grams of 1 to 2-mm air-dried soil aggregates in a sieve were slowly pre-moistened with distilled water to prevent slaking of the aggregates, then the filled sieve was placed into a can filled with distilled water. To determine aggregate stability, the sieve (60 mesh) was immersed for 5 minutes then the sieve was lowered and raised for 3

minutes with a stroke of 1.3 cm, at about 34 strokes/min. Unstable aggregates slaked and/or dispersed and resultant fine materials passed through the sieve and were collected in the water-filled can underneath the sieve. After this fixed time, the liquid was removed and water containing 2 g L⁻¹ sodium hexametaphosphate was added to the can for soils with pH > 7 or 2 g L⁻¹ NaOH for soils with pH < 7 and the remaining soil was wet sieved to disperse remaining aggregates and separate the sand fraction from the silt and clay fractions. The aggregates that remained stable after 3 minutes of sieving were gently rubbed across the screen with a rubber tipped rod so that all aggregates were destroyed and the fine residue on the sieve was washed into the collecting can. Sand grains and plant roots remained on the sieve so that the mass of aggregates could be calculated by difference. After drying the suspensions with the disaggregated material from the aggregates, the weight of both stable and unstable aggregates were determined. Dividing the weight of stable aggregates by the total aggregate weight gives an index of aggregate stability. Statistical analysis of data was limited to regression analysis and utilised Statview software (StatSoft Inc. 2003).

Chemical Analyses

Soil pH

Soil pH was determined in water and 1N KCl at a solid to solution ratio of 1:1 and in water for a saturation paste. The contents were stirred with a glass rod for 30 minutes before measuring the pH by a standardized pH meter (National Soil Survey Center, 1996).

Organic Matter (OM)

The organic matter content of soil was indirectly estimated through multiplication of the organic carbon concentration by 1.724. The organic carbon was determined according to the Walkley and Black wet oxidation procedure. This involved wet combustion of organic carbon with a mixture of potassium dichromate and sulfuric acid. After reaction the residual dichromate was titrated against ferrous sulfate (Nelson and

Sommers, 1996). A weight of 1.0 g of soil (< 0.5 mm) was placed in a 250 mL Erlenmeyer flask. Five mL of 1 N $K_2Cr_2O_7$ was added and the flask was swirled gently to disperse the soil into suspension. Then 10 mL of concentrated H_2SO_4 was added to the flask, swirled gently until the soil and reagents were mixed. The solution took on a greenish cast and then changed to dark green. The flask was allowed to stand with occasional swirling for 30 minutes. Then 30 mL of deionized water was added to the flask, swirled gently then 3-4 drops of o-phenanthroline indicator were added and the solution was titrated with 1 N $FeSO_4$ until the color changed to a red end point.

Total Nitrogen

A ground soil weighing 1.0 g for clayey and 3.0 for sandy soil was placed in micro kjeldahl flask and digestion mixture solution 5 mL were added, swirled vigorously and digested, rotating the flask frequently until fumes were emitted. Continued digestion for at least 1 hour after mixture became white. Cooled to room temperature and added water made up to about 50 mL. Shake until the contents of the flask were thoroughly mixed. The contents were next filtered using No. 5 Whatman filter paper. The 10 mL of aliquot was placed in distillation flask and 5 mL of 10 N NaOH was added. Distilled for 7 minutes, added 5 mL H_3BO_3 acid indicator for containing NH_3 . And, titrated the absorbed ammonia with 0.01 N H_2SO_4 until color changed from green to an end point of pink color (Jackson, 1965).

Available Phosphorus

A soil sample weighing 3 g was placed in the 250 mL flask and added Bray II extracting solution 30 mL, shaken for 40 seconds. The contents were filtered with No. 42 Whatman filter paper. Aliquot 1-10 mL was pipetted in volumetric flask 25 mL and adjusted by distilled water. After 10 minutes, solution was transferred to tubes for determining by spectrophotometer at wavelength 882 mili-micron. A standard curve for 0, 0.2, 0.4, 0.6, 0.8 and 1.0 mg P kg^{-1} was prepared (Bray and Kurtz, 1945).

Extractable Bases

The bases (Ca^{2+} , Mg^{2+} , Na^{+} and K^{+}) that are extracted by NH_4OAc extraction are generally exchangeable bases located on the cation exchange sites of the soil (Chapman, 1965). A soil sample weighing 10 g for clayey and 25 g for sandy soil was placed in an Erlenmeyer flask and approximately 50 mL 1 N NH_4OAc , at pH 7.0, were added, swirled and allowed to stand overnight. The contents were next filtered using a Buchner funnel with No. 42 Whatman filter paper and a 250 mL suction flask. The volume of the extract was made up to 100 mL. Calcium, Mg, K and Na contents in the leachate were determined by atomic absorption spectrophotometry.

Extractable Acidity

Extractable acidity is the acidity released from the soil by barium chloride-triethanolamine solution buffer ($\text{BaCl}_2\text{-TEA}$) at pH 8.2 (Thomas, 1987b). It includes all acidity generated by replacement of the hydrogen and aluminum ions from permanent and pH-dependent exchange sites. A soil sample weighing 4 g was placed in an Erlenmeyer flask and 100 mL of buffer solution at 8.2 (0.5 N $\text{BaCl}_2 \cdot \text{H}_2\text{O}$ and 2 N triethanolamine) were added. The contents were topped by rubber bung, shaken for 30 min, left to stand overnight and shaken 30 min then left for 2 hours. Taken 50 mL of the content by using the pipette controller, placed to new Erlenmeyer flask. The extracts were added 3 drops of mixed indicator (bromocresol green and methyl red in 95% ethyl alcohol). The extract was titrated with 0.2 N HCl. The acid was added drop by drop until the color changed from green to an end point of purplish red color. The buffer solution was titrated with 0.2 N HCl as the blank in the same condition as extract samples. The amount of HCl consumed was used to calculate the extractable acidity expressed as $\text{cmol H}^{+} \text{ kg}^{-1}$.

Cation Exchange Capacity (CEC)

The CEC is defined as the sum total of the exchangeable cations that a soil can adsorb. It is dependent upon the negative charges of soil component. Two main methods of CEC determination were used (Thomas, 1987a; National Soil Survey Center, 1996):

The CEC by NH_4OAc at pH 7.0 was determined by saturating the exchange sites with an index cation (NH_4^+), washing the soil free of entrained index cation, displacing the index cation (NH_4^+) adsorbed by soil and measuring the index cation. A soil sample weighing 10 g for clayey and 25 g for sandy soils was placed in an Erlenmeyer flask, to which 50 mL of 1N NH_4OAc , pH 7.0 were added. The flask was stirred occasionally and allowed to stand overnight. The contents were filtered by the Buchner funnel procedure. The soil was next given 6 washings with 25 mL of 1N NH_4OAc , and 5 washings with 25 mL of 95% ethyl alcohol. The aliquots from these washings were discarded. The index cation was next displaced by giving 6 washings with 25 mL of 10% acidified NaCl, and filtrates were collected in filtering flasks. The filtrates were transferred to a Kjeldahl flask to which 25 mL of 50% NaOH were added. Fifty mL of 4% boric acid was placed into a 100 mL flask and 5 drops of bromocresol green methyl red indicator were added. The Kjeldahl flask was connected to the distillation unit and the boric solution flask with condenser, and was then distilled for 30 min. The solution was titrated with 0.01 N H_2SO_4 until color changed from green to the pink end point. The volume of H_2SO_4 was recorded and used to calculate the CEC as cmol (+) kg^{-1} .

The cation exchange capacity (CEC) at pH 8.2 was calculated by summing the NH_4OAc extractable bases plus the BaCl_2 -TEA extractable acidity (at pH 8.2) (National Soil Survey Center, 1996).

Base Saturation

Base saturation percentage by NH_4OAc at pH 7.0 is equal to the sum of bases extracted by NH_4OAc , divided by the CEC by NH_4OAc , and multiplied by 100. Base saturation percentage by sum of cations is equal to the sum of bases extracted by NH_4OAc , divided by the CEC by sum of cations, and multiplied by 100. (National Soil Survey Center, 1996).

Electrical Conductivity (EC)

Electrical conductivity (EC) by the saturation extract method at 25°C and measured by electrical-conductivity bridge (U.S. Salinity Laboratory Staff, 1954).

Sodium Adsorption Ratio (SAR)

The SAR was computed by dividing the molar concentration of the monovalent cation Na^+ by the square root of the sum of the molar concentration of the divalent cations Ca^{2+} and Mg^{2+} (meq L^{-1}) (U.S. Salinity Laboratory Staff, 1954). The saturation extract cations Ca^{2+} , Mg^{2+} and Na^+ measured by atomic absorption spectrophotometer (National Soil Survey Center, 1996).

Exchangeable Sodium Percentage (ESP)

The ESP was computed by dividing the exchangeable sodium (ES) by the CEC-7 and multiplying by 100 (U.S. Salinity Laboratory Staff, 1954).

Mineralogical Analysis

X-Ray Diffraction (XRD) for Clay and Silt Fraction Samples. The clay fraction for mineralogical analysis was separated by using a sedimentation procedure. Pre-treatments of the 2 mm soil to remove organic carbon were by using H_2O_2 (Gee and Bauder, 1986). The clay fraction for mineralogical analysis was separated using the same method with particle size analysis in above procedure to obtain 10 g of clay fraction. The clay suspension was next flocculated by adding excess solid NaCl , and the supernatant was then decanted. The flocculated clay was transferred to a centrifuged tube to wash and remove free excess salt. The Dithionite-Citrate-Bicarbonate method (DCB) was used to remove iron. The dialysis method was used to remove salt from the clay fraction. The DI water overriding the dialysis tube was replaced several times until the conductivity of the water was equal to that of the DI water.

X-ray diffraction analysis was used to identify and to make semiquantitative measurements of the crystalline mineral components of the clay fraction. The clay fraction from sedimentation was pretreated using 4 treatments. The clay after Mg^{2+} and K^+ saturation were placed on ceramic plates, washed with $\approx 10\%$ glycerol on the Mg^{2+} saturation plates for the glycerol treatment, and heated to 550°C for the K^+ saturation plate for heat treatment (Brindley and Brown, 1980). Minerals were determined for all horizons by X-ray diffraction (XRD) analysis using a monochromatised $\text{CuK}\alpha$ radiation with a Philips PW-3020 diffractometer ($\text{Cu K}\alpha$, 50kV, 20mA). Clay fractions were scanned respectively from 4 to $45^\circ 2\theta$, using a step size of $0.02^\circ 2\theta$ and a scan speed of $0.04^\circ 2\theta \text{ sec}^{-1}$. Silt was prepared as a random powder for some horizons and analyzed using a Philips X'Pert diffractometer ($\text{Co K}\alpha$, 50kV, 20mA), scanned from 4 to $65^\circ 2\theta$.

Relative proportions of various minerals were calculated by comparing the XRD peak intensity with the intensity for standard minerals (Brindley and Brown, 1980).

Micromorphological Analysis

Preparation

Kubiena samples were transferred to impregnation mould containers, oven dried at $60\text{--}70^\circ\text{C}$ for approximately 2-4 week. Before oven drying acetone was used to replace water in micro-pore as it is easily volatilized from the samples. This is special consideration for salt affected soils and clay texture soil for reducing the impregnation problem due to soil moisture. The soil samples were impregnated with a 40:60 resin: monostyrene mixture and 5 g of the catalyst benzoyl peroxide ($\text{C}_{14}\text{H}_{10}\text{O}_4$) per liter. The resin mixture was poured onto samples at atmospheric pressure, followed by a period in a vacuum oven while the pressure was slowly increased from 10 to 65 cm Hg, and then the samples were left for 4 hours. The dried impregnated samples were cut to the size of glass slides, polished on one face to smooth and then cleaned with acetone. Blocks were mounted on glass slides with resin and polished to 0.03 mm thickness.

Optical Analysis

The thin sections were analyzed under a polarizing microscope using standard micromorphological techniques as described by Bullock *et al.* (1985).

SEM Analysis of Soil Thin Section

The polished thin section samples were first analyzed by optical microscopy. The areas of interest were selected and coated with carbon for examination using a backscattered electron image, secondary electron image and elemental mapping on both a VPSEM ZEISS 1555 SEM and a JEOL 6400 SEM operated at 15 kV of electron beam accelerating voltage. Energy dispersive spectrometer (EDS) quantitative microanalysis was used to determine the chemical composition of distinct micromorphological features (White and Dixon, 1995) such as soil matrix, clay coat, mottle and nodule. The EDS detector used was a Be-window Oxford Instruments Link Analytical detector running ISIS software and the analysis results were standardized based on standard natural minerals, metals and synthetic compounds.

GIS Analysis

The data set for the analysis consisted of soil map of salt affected area (Department of Land Development, 2003), geologic map (Geological Survey Division Staff, 1985), topographic map (The Royal Thai Survey Department, 1984) and rainfall data of Thailand (Meteorological Department of Thailand, 2006). The databases were created by converting features on maps to digital format layer including salt affected area, geology and rainfall layers. Each layer comprises spatial data and attribute data. Isohyetal line layer was generated from the average rainfall layer by Inverse Distance Weighted Interpolation Method (Aguilar *et al.*, 2005; Chaplot *et al.*, 2006). Overlaying was used to analyze the distribution trends of salt affected soils and the relationship between these soils and spatial factors.

Appendix C
Appendix table

Appendix Table C1 Physical properties of Salt Affected Soils.

Horizon	Depth (cm)	Particle size distribution (g kg ⁻¹)			Textural class	Bulk density (Mg m ⁻³)	K sat (cm hr ⁻¹)
		Sand	Silt	Clay			
<u>Pedon 1</u>	<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>						
Apn	0-15	8559	7	48	LS	1.55	139.32
Apng	15-30/40	526	303	171	L	1.98	2.58x10 ⁻¹
Btng1	40-55/60	481	340	179	L	2.17	
Btng2	60-87	536	265	199	SL	1.17	
Btng3	87-144	290	274	336	CL	1.96	
Btng4	114-150	515	207	278	SCL	2.04	
Btng5	150-172	602	179	219	SCL	1.82	
Btng6	172-180+	527	195	278	SCL	1.96	
<u>Pedon 2</u>	<i>Vertic Natraqualf, fine-loamy, mixed, isohyperthermic</i>						
Ang	0-19	182	330	515	C	1.79	1.03x10 ⁻³
Btng1	19-38	160	334	506	C	1.77	1.71x10 ⁻³
Btng2	38-56	184	259	557	C	1.8	4.97x10 ⁻²
Btng3	56-77	298	211	491	C	1.89	
2Btng4	77-100	520	182	298	SCL	1.88	
2Btng5	100-119	808	40	152	SL	2.43	
2Btng6	119-146	875	24	101	LS	2.15	
2Btng7	146-175	721	120	159	SL	1.79	
2Btng8	175-210+	655	140	205	SCL	1.73	
<u>Pedon 3</u>	<i>Vertic Natraqualf, fine-loamy, mixed, semiactive, isohyperthermic</i>						
Ang	0-21	176	311	513	C	1.79	1.82x10 ⁻³
Btng1	21-41	174	317	509	C	1.83	1.06x10 ⁻³
Btng2	41-66	167	316	517	C	1.83	1.06x10 ⁻³
Btng3	66-88	105	248	647	C	1.94	
Btng4	88-108	75	197	728	C	1.96	
Btng5	108-132	58	93	849	C	1.96	
Btng6	132-165	38	3	959	C	1.89	
Btng7	165-184	66	19	915	C	1.89	
Btng8	184-202+	55	43	902	C	1.92	
<u>Pedon 4</u>	<i>Typic Natraqualf; coarse-loamy, mixed, ishyperthermic</i>						
Apng	0-12	685	229	86	SL	1.73	7.81x10 ⁻²
Bng	12-37	727	184	89	SL	1.61	3.52x10 ⁻²
Btng1	37-60	728	143	129	SL	1.61	1.61x10 ⁻¹
Btng2	60-76	650	172	178	SL	1.74	
Btng3	76-100	609	188	203	SCL	1.99	
Btng4	100-128	693	137	170	SL	1.79	
Btng5	128-140	786	80	134	SL	1.81	
2Btng6	140-170	676	154	170	SL	1.85	
2Btng7	170-190+	708	138	154	SL	1.80	
<u>Pedon 5</u>	<i>Typic Natraqualf, fine-loamy, mixed, isohyperthermic</i>						
Apng1	0-13	760	148	92	SL	1.79	5.55x10 ⁻¹
Apng2	13-28	741	143	116	SL	1.72	1.85x10 ⁻¹
Btng1	28-53	702	159	140	SL	1.84	6.65x10 ⁻³
Btng2	53-80	587	233	180	SL	1.88	
2Btng1	80-100	415	349	326	L	1.94	
2Btng2	100-120	372	344	284	CL	1.90	
2Btng3	120-145	278	406	316	CL	1.96	
2Btng4	145-178	286	390	324	CL	1.93	
2Btng5	178-200+	321	343	336	CL	1.84	

Appendix Table C1 (Continued)

Horizon	Depth (cm)	Particle size distribution (g kg ⁻¹)			Textural class	Bulk density (Mg m ⁻³)	K sat (cm hr ⁻¹)
		Sand	Silt	Clay			
Pedon 6 <i>Typic Natraqualf; fine, mixed, isohyperthermic</i>							
App1	0-15	322	390	288	CL	1.51	1.80
App2	15-32/36	171	377	452	C	1.94	1.00x10 ⁻²
ABng	36-57	154	418	428	SiC	2.04	5.08x10 ⁻³
Btng1	57-87	165	402	432	C	2.00	
Btng2	87-115	200	400	40	C	1.94	
Btng3	115-144	657	171	172	SC	1.87	
Btng4	144-160/162	84	44	116	LS	1.74	
Btng5	162-195+	474	246	280	SCL	1.98	
Pedon 7 <i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>							
Apng1	0-20/30	919	17	64	S	1.69	19.62x10 ³
Apng2	32-52/55	429	325	183	L	1.73	7.78x10 ⁻¹
Btng1	55-76/81	598	208	194	SL	2.03	
Btng2	81-115/118	633	209	158	SL	1.99	
Btng3	118-130/137	581	126	193	SCL	1.89	
Btng4	137-150/163	590	120	290	SCL	1.92	
Btng5	163-190	674	75	251	SCL	2.10	
Pedon 8 <i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>							
Apng	0-20	382	473	145	L	1.88	2.25
Btng1	20-45/50	377	374	249	L	1.69	4.86x10 ⁻¹
Btng2	50-65/70	328	412	258	L	1.83	
Btng3	70-95/100	342	422	236	SCL	1.96	
Btng4	100-112/120	548	203	249	SCL	1.94	
Btng5	120-130/138	328	432	240	L	1.75	
Btng6	138-160/170	287	367	346	CL	1.9	
2Cng1	170-172/175	566	129	305	SCL	1.78	
2Cng2	175-200	548	283	477	C	1.98	
Pedon 9 <i>Typic Natraqualf; fine, mixed, isohyperthermic</i>							
Apng	0-13/15	455	203	342	CL	1.80	1.34
Btng1	15-37/40	346	211	426	C	1.98	8.30x10 ⁻³
Btng2	43-72/73	328	224	448	C	2.04	
Ckng1	73-96	391	222	407	C	2.03	
Ckng2	96-123/126	334	227	438	C	2.27	
Ckng3	126-190	454	158	388	SC	2.16	
Pedon 10 <i>Typic Natraqualf; loamy-skeletal, mixed, isohyperthermic</i>							
Apng	0-12/15	819	141	40	LS	1.81	1.20
Btcng	15-32/36	717	103	180	SL	2.11	1.62x10 ⁻¹
Btng1	36-60	624	120	256	SCL	2.15	5.42x10 ⁻³
Btng2	60-85	576	156	268	SCL	2.08	
Btng3	85-106	584	140	276	SCL	1.95	
Btng4	106-125/130	636	116	248	SCL	2.07	
BCng	130-156	600	160	240	SCL	1.88	
Crng1	156-182	165	399	436	C	1.78	
Crng2	182-203+	239	470	292	CL	1.72	
Pedon 11 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apng1	0-10	352	168	403	C	1.78	8.75x10 ⁻²
Apng2	10-20	287	168	545	C	1.76	1.95x10 ⁻³
Btng1	20-33	332	172	490	C	1.87	4.30x10 ⁻³
Btng2	33-48	406	192	402	C	1.84	
Btng3	48-70	381	200	419	C	1.94	
Btng4	70-88	423	216	361	CL	1.90	
2Btng5	88-114	477	200	323	SCL	1.87	
2Btng6	114-135	514	201	285	SCL	1.77	

Appendix Table C1 (Continued)

Horizon	Depth (cm)	Particle size distribution (g kg ⁻¹)			Textural class	Bulk density (Mg m ⁻³)	K sat (cm hr ⁻¹)
		Sand	Silt	Clay			
2Btng7	135-156	580	178	242	SCL	1.75	
2Btng8	156-190	699	97	204	SCL	1.80	
<u>Pedon 12</u> <i>Typic Natraqualf; very fine, kaolinitic, isohyperthermic</i>							
Apg1	0-18	235	261	504	C	1.87	1.10x10 ⁻³
Apg2	18-30	190	290	520	C	1.75	1.44x10 ⁻³
Btg	30-42	234	267	499	C	1.68	1.21x10 ⁻³
Btng1	42-53/64	135	226	639	C	1.84	
Btng2	64-79	155	201	644	C	1.86	
Btng3	79-100	135	219	646	C	1.82	
Btng4	100-124	172	272	556	C	1.87	
Btng5	124-151	234	275	491	C	1.94	
2Btng6	151-176	363	242	395	CL	1.88	
2Btng7	176-200	628	104	268	SCL	1.81	
<u>Pedon13</u> <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apg	0-11	213	264	523	C	1.80	1.04x10 ⁻³
Btg1	11-32	132	206	662	C	1.78	9.51x10 ⁻³
Btg2	32-56	164	228	608	C	1.82	2.11x10 ⁻²
Btng1	56-65/85	180	253	567	C	1.85	
Btng2	85-110	167	265	568	C	1.92	
Btng3	110-124	181	211	608	SiL	1.93	
2Btng4	124-152	80	71	849	C	1.85	
2Btng5	152-180+	174	186	640	C	1.92	
<u>Pedon 14</u> <i>Typic Endoaqualf; fine, kaolinitic, isohyperthermic</i>							
Apg1	0-10	424	229	347	CL	1.62	3.84
Apg2	10-22	403	234	363	CL	1.88	1.53x10 ⁻³
Btg1	22-38	315	229	456	C	1.68	2.81x10 ⁻²
Btg2	38-60	224	225	551	C	1.79	
Btg3	60-83	259	222	519	C	1.93	
Btg4	83-102	250	285	465	C	1.91	
2Btg5	102-121	346	289	365	CL	1.87	
2Btg6	121-140	395	292	313	CL	1.84	
2Btg7	140-162	522	208	270	SCL	1.81	
2Btg8	162-190	556	208	236	SCL	1.75	
<u>Pedon 15</u> <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apg	0-16	363	290	348	CL	1.51	2.40
Btg1	16-31	254	283	463	C	1.74	2.76x10 ⁻³
Btg2	31-52	202	282	516	C	1.78	3.25x10 ⁻²
Btg3	52-69	203	244	553	C	1.83	
Btg4	69-95	130	274	596	C	1.79	
2Btng1	95-128	164	302	534	C	1.84	
2Btng2	128-161	180	285	535	C	1.93	
2Btng3	161-187	223	291	486	C	1.96	
2Btng4	187-210+	294	325	381	CL	1.93	
<u>Pedon16</u> <i>Aeric Kandiaqualf; fine-loamy, mixed, isohyperthermic</i>							
Apng	0-18	637	188	175	SL	1.654	1.96x10 ⁻¹
Btng1	18-36	629	162	209	SL	1.777	1.18x10 ⁻¹
Btng2	36-63	605	182	213	SCL	1.784	
Btng3	63-101	608	192	200	SL	1.831	
Btkg	101-123	507	217	276	SCL	2.029	
BCKg	123-135	351	273	376	CL	1.943	
Ckg1	135-160	198	217	585	C	1.935	
Ckg2	160-195	169	268	563	C	1.907	

Appendix Table C1 (Continued)

Horizon	Depth (cm)	Particle size distribution (g kg ⁻¹)			Textural class	Bulk density (Mg m ⁻³)	K sat (cm hr ⁻¹)
		Sand	Silt	Clay			
Pedon 17 <i>Typic Natraqualf; sandy, silicious, isohyperthermic</i>							
Apng	0-11	867	67	66	LS	1.75	6.62x10 ⁻¹
Bng1	11-30	875	79	46	LS	1.67	1.09
Bng2	30-47	853	98	49	LS	1.61	2.33
Btng1	47-69	847	99	54	LS	1.64	
Btng2	69-95	803	59	138	SL	1.82	
Btng3	95-110	779	73	148	SL	1.76	
Btng4	110-130	778	74	148	SL	1.82	
Btng5	130-153	757	90	153	SL	1.87	
2Btng6	153-178	636	128	236	SCL	2.00	
2Btng7	178-200+	564	157	279	SCL	1.86	
Pedon 18 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apng	0-20/23	330	462	208	L	1.82	6.30x10 ⁻²
Btng1	23-35/42	78	566	356	SiCL	1.70	1.39x10 ⁻²
Btng2	42-62/72	78	544	378	SiCL	1.66	
Btng3	72-98/118	490	459	492	SiC	1.80	
Btng4	118-122/137	60	286	658	C	1.94	
Btng5	137-162/168	44	274	682	C	1.88	
Btng6	168-193	220	184	493	C	1.88	
Pedon 19 <i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>							
Apng	0-13/16	799	112	89	LS	1.55	12.88x10 ⁻²
Bng1	13-35/37	697	128	175	SL	1.74	196.20
Bng2	37-68	772	105	123	SL	2.49	
Btng1	68-86	676	98	226	SCL	1.70	
Btng2	86-100	637	159	202	SCL	1.67	
Btng3	100-108/120	594	217	188	SL	1.91	
Btng4	120-125/131	413	209	378	CL	1.77	
Cng	131-160	750	165	85	SL	1.89	
Pedon 20 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apg	0-15/23	642	248	110	SL	1.53	3.21x10 ⁻¹
Bcg	23-46	338	246	416	C	1.99	2.81x10 ⁻¹
Btg1	46-65	253	291	456	C	1.95	3.62x10 ⁻¹
Btg2	65-88	276	309	415	C	1.90	
Btg3	88-113	297	334	369	CL	1.90	
2Btng1	113-140	331	348	321	CL	1.86	
2Btng2	140-172	328	377	295	CL	1.91	
2Btng3	172-205+	254	415	331	CL	1.94	
Pedon 21 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>							
Apg	0-19/20	636	291	73	SL	1.53	6.02x10 ⁻¹
Apng	20-27/32	697	246	57	SL	1.68	4.93x10 ⁻¹
Bcg	32-54/63	450	214	336	SCL	1.90	2.11x10 ⁻¹
Btg1	63-82/87	334	231	435	C	1.99	
Btg2	87-111/114	336	271	393	CL	1.98	
2Btg3	114-137	334	340	326	CL	1.94	
2Btg4	137-155	326	304	370	CL	1.91	
2Btng1	155-183	381	297	322	CL	1.91	
2Btng2	183-207+	343	374	283	CL	1.88	

^A LS= loamy sand, SL= sandy loam, L= loam, SCL= sandy clay loam, CL= clay loam, SC= sandy clay, SiC= silty clay, C= clay

Appendix Table C2 Chemical properties of Salt affected Soils.

Horizon	Depth	pH		OM	Total N	Avai. P	Avai. K	Exchangeable bases				Sum bases	EA	CEC		BS		EC (sat.)	SAR	ESP
		H ₂ O	KCl					Ca	Mg	K	Na			Sum NH ₄ OAc	Sum NH ₄ OAc					
	(cm)			(...g kg ⁻¹ ...)	(...mg kg ⁻¹ ...)			(.....cmol kg ⁻¹)						(.....%.....)		(.....%.....)		dSm ⁻¹		%
<u>Pedon 1</u>	Typic Natraqualf; coarse-loamy, mixed, isohyperthermic																			
Apn	0-15	4.8	4.8	4.92	1.60	3.0	28.9	2.22	1.62	0.07	25.85	29.76	6.16	35.92	6.54	82.85	455.56	111.5	234.7	375.2
Apg	15-30/40	4.8	4.2	5.26	2.20	4.7	34.2	1.00	0.62	0.08	8.43	10.13	6.16	16.29	46.24	62.19	21.95	51.3	116.4	18.2
Btg1	40-55/60	5.8	5.0	3.75	5.90	0.1	37.6	1.88	0.78	0.09	12.43	15.18	14.96	30.14	30.00	50.36	50.04	23.3	129.5	40.8
Btg2	60-87	6.3	5.2	3.51	4.50	0.6	34.6	1.17	0.78	0.08	6.07	8.10	6.16	14.26	13.75	56.80	59.03	14.65	77.1	44.2
Btg3	87-114	6.6	5.5	3.08	2.70	0.2	36.7	2.07	1.42	0.09	6.27	9.85	6.97	16.82	30.22	58.56	3.64	8.6	59.5	20.7
Btg4	114-150	7.2	5.9	1.09	2.50	0.3	48.9	2.52	1.85	0.12	6.20	10.69	3.76	14.45	18.04	73.98	59.50	6.7	52.8	34.4
Btg5	150-172	7.2	5.9	1.35	2.20	0.4	46.7	2.53	1.58	0.11	5.57	9.79	6.16	15.95	16.01	61.38	61.28	6.9	48.5	34.8
Btg6	172-180+	7.3	6.1	0.51	2.00	0.4	48.4	2.32	1.58	0.12	5.13	9.15	10.96	20.11	18.72	45.50	48.87	6.0	46.2	27.4
<u>Pedon 2</u>	Vertic Natraqualf, fine-loamy, mixed, isohyperthermic																			
Ang	0-19	5.5	4.5	11.6	0.44	2.4	151.6	14.88	3.00	0.39	4.44	22.71	15.76	38.47	23.06	59.04	125.20	7.8	9.0	19.2
Btng1	19-38	5.0	4.3	7.67	0.30	0.8	75.9	11.08	2.25	0.19	3.87	17.39	16.08	33.47	16.24	51.95	137.58	11.7	9.1	23.8
Btng2	38-56	4.7	3.9	6.27	0.26	0.4	72.1	16.98	2.55	0.18	4.28	23.99	17.03	41.02	24.30	58.48	121.38	11.6	8.3	17.6
Btng3	56-77	4.9	4.0	3.78	0.19	0.4	40.1	12.45	2.27	0.10	4.22	19.06	14.67	33.72	19.07	56.51	236.46	11.8	7.9	22.2
2Btng4	77-100	5.2	4.4	1.94	0.10	0.4	23.7	8.17	1.52	0.06	2.77	12.52	10.92	23.44	10.59	53.43	159.66	13.4	7.7	26.2
2Btng5	100-119	5.9	5.2	1.39	0.05	0.8	17.0	5.65	0.83	0.04	1.43	7.96	7.48	15.44	4.38	51.57	263.64	22.1	7.7	32.7
2Btng6	119-146	5.8	5.5	1.21	0.03	1.1	7.8	1.98	0.57	0.02	0.89	3.46	8.35	11.82	2.60	29.30	262.22	22.6	7.4	34.2
2Btng7	146-175	6.0	5.7	1.05	0.05	1.4	19.0	5.80	1.06	0.05	2.01	8.92	8.13	17.05	5.91	52.29	216.73	18.6	9.3	33.9
2Btng8	175-210+	6.0	5.5	0.70	0.03	6.7	26.9	10.32	1.42	0.07	2.04	13.85	9.13	22.97	8.03	60.27	229.43	42.1	9.1	25.4
<u>Pedon 3</u>	Vertic Natraqualf, fine-loamy, mixed, semiactive, isohyperthermic																			
Ang	0-21	4.8	4.3	14.4	0.65	6.1	182.0	21.12	2.83	0.47	5.29	29.70	16.59	46.29	21.88	64.16	172.03	23.9	8.3	24.2
Btng1	21-41	4.8	3.9	8.45	0.33	1.2	63.5	24.59	2.22	0.16	5.57	32.54	16.85	49.39	19.09	65.89	202.27	17.7	7.4	29.2
Btng2	41-66	4.5	3.8	5.77	0.26	0.8	50.3	19.61	2.76	0.13	5.59	28.09	16.17	44.26	20.67	63.47	177.33	18.8	6.7	27.1
Btng3	66-88	4.6	4.2	3.28	0.20	0.8	63.3	27.97	4.19	0.16	7.40	39.72	16.96	56.68	27.46	70.09	190.21	24.3	7.1	26.9
Btng4	88-108	4.9	4.2	3.35	0.20	0.8	67.8	32.31	5.47	0.17	8.11	46.06	18.02	64.08	34.58	71.88	175.18	21.9	6.6	23.5
Btng5	108-132	5.1	4.7	2.63	0.18	0.8	97.0	33.58	6.73	0.25	9.58	50.15	18.35	68.51	38.36	73.21	171.73	19.2	6.6	25.0
Btng6	132-165	5.3	4.8	2.66	0.30	1.0	119.8	35.45	7.35	0.31	12.20	55.31	20.25	75.56	42.98	73.20	163.56	16.8	6.9	28.4
Btng7	165-184	5.1	4.9	2.07	0.41	1.4	133.0	36.43	6.41	0.34	12.55	55.73	19.52	75.25	41.85	74.06	156.56	12.1	6.5	30.0
Btng8	184-202+	5.4	5.0	2.25	0.39	1.3	141.1	35.11	6.35	0.36	12.66	54.48	19.35	73.83	42.87	73.79	147.67	7.9	5.7	29.5

Appendix Table C2 (Continued)

Horizon	Depth (cm)	pH		OM	Total N	Avai. P	Avai. K	Exchangeable bases				Sum bases	EA	CEC		BS		EC (sat.) dSm ⁻¹	SAR	ESP %
		H ₂ O	KCl					Ca	Mg	K	Na			Sum	NH ₄ OAc	Sum	NH ₄ OAc			
				(...g kg ⁻¹ ...)	(...mg kg ⁻¹ ...)			(.....cmol kg ⁻¹)						(.....%.....)						
Pedon 4 <i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>																				
Apng	0-12	8.1	7.8	3.25	0.09	12.4	24.7	5.62	0.87	0.06	0.85	7.42	0.61	8.03	1.33	92.38	2195.24	114.3	77.3	64.2
Bng	12-37	8.5	6.9	1.04	0.05	3.5	18.0	0.53	0.34	0.05	0.98	1.89	2.08	3.97	1.61	47.54	221.42	8.9	25.4	60.9
Btng1	37-60	8.3	6.7	0.69	0.05	1.6	26.2	0.69	0.50	0.07	1.53	2.79	1.49	4.28	2.87	65.15	158.07	9.5	25.9	53.4
Btng2	60-76	8.3	6.7	0.70	0.05	1.6	39.2	1.29	0.75	0.10	2.13	4.26	1.81	6.07	5.58	70.21	124.23	8.9	23.4	2.0
Btng3	76-100	8.7	7.2	0.70	0.06	0.6	51.5	8.90	0.96	0.13	2.65	12.65	2.10	14.76	6.51	85.74	240.85	6.8	22.2	40.7
Btng4	100-128	8.2	6.6	0.70	0.04	0.2	45.9	1.13	0.73	0.12	2.53	4.51	2.42	6.94	5.53	65.05	135.74	8.6	23.7	45.8
Btng5	128-140	7.5	6.9	0.52	0.02	0.2	39.9	0.73	0.55	0.10	1.93	3.31	2.70	6.02	4.30	55.07	145.01	7.4	25.2	44.9
2Btng6	140-170	7.6	6.2	0.35	0.02	0.2	46.0	1.10	0.77	0.12	2.98	4.97	2.72	7.69	5.79	64.66	135.70	7.2	25.1	51.5
2Btng7	170-190+	7.6	6.4	0.52	0.01	3.6	43.2	0.83	0.63	0.11	2.20	3.76	2.12	5.88	4.45	63.99	156.50	11.9	26.1	49.3
Pedon 5 <i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>																				
Apng1	0-13	7.1	6.8	4.40	0.06	5.5	10.8	2.10	0.34	0.03	11.02	13.49	2.25	15.99	1.75	84.37	770.86	315.0	114.1	629.8
Apng2	13-28	7.3	6.9	2.40	0.07	1.8	12.4	1.06	0.27	0.03	6.60	7.96	1.30	9.26	4.35	85.96	182.99	62.0	69.3	151.6
Btng1	28-53	7.4	6.4	1.50	0.04	0.7	13.2	1.21	0.35	0.03	6.85	8.44	5.50	13.94	11.38	60.55	74.17	47.0	68.1	60.2
Btng2	53-80	7.6	6.7	1.70	0.07	0.6	13.1	1.38	0.37	0.03	6.71	8.49	2.70	11.19	8.11	75.87	104.69	29.0	57.9	82.7
2Btng1	80-100	7.7	7.2	1.10	0.07	1.1	20.2	2.24	0.48	0.05	6.40	9.17	5.80	14.97	19.80	61.26	46.31	18.5	58.7	32.3
2Btng2	100-120	7.9	6.8	1.60	0.03	0.6	28.3	1.98	0.56	0.07	6.85	9.46	8.20	17.66	12.88	53.57	73.45	17.7	64.2	53.2
2Btng3	120-145	8.0	7.1	1.70	0.03	1.5	35.4	2.71	0.59	0.09	5.56	8.95	5.80	14.75	16.34	60.68	54.77	14.8	64.9	34.0
2Btng4	145-178	8.3	7.3	1.60	0.03	0.6	44.7	5.55	0.77	0.11	7.72	14.15	5.00	19.15	21.06	73.89	67.19	11.2	35.7	36.7
2Btng5	178-200+	8.2	7.4	1.50	0.06	0.6	42.0	5.22	0.78	0.11	6.84	12.95	4.50	17.45	15.97	74.21	81.09	11.8	44.3	42.9
Pedon 6 <i>Typic Natraqualf; fine, mixed, isohyperthermic</i>																				
Apg1	0-15	5.3	4.5	15.60	0.25	1.0	22.1	6.32	1.53	0.06	5.09	13.00	10.20	23.20	10.99	56.03	118.29	52.5	9.6	46.3
Apg2	15-32/36	5.0	4.0	10.10	0.31	0.3	20.6	5.75	1.55	0.05	3.51	10.86	15.50	26.36	28.04	41.20	38.73	9.5	7.0	12.5
ABng	36-57	5.9	4.9	5.50	0.07	0.3	16.4	5.37	1.45	0.04	3.88	10.74	12.20	22.94	22.13	46.82	48.53	9.6	8.6	17.6
Btng1	57-87	6.4	5.1	4.20	0.14	0.4	18.6	5.96	1.64	0.05	4.85	12.50	7.30	19.80	20.44	63.13	61.15	10.8	11.0	23.8
Btng2	87-115	6.5	5.1	5.00	0.21	0.8	14.4	5.54	1.46	0.04	5.31	12.35	6.30	18.65	20.31	66.22	60.81	11.1	12.1	26.1
Btng3	115-144	6.2	5.1	2.80	0.10	0.3	7.7	3.16	0.70	0.02	3.81	7.69	3.50	11.19	21.46	68.72	35.83	19.2	16.9	17.8
Btng4	144-160/162	6.2	5.5	2.70	0.16	0.3	9.8	2.34	0.43	0.03	3.37	6.17	4.40	10.57	21.50	58.37	28.70	43.5	2.7	15.7
Btng5	162-195+	6.7	5.4	2.20	0.03	0.5	19.2	3.57	0.89	0.05	4.37	8.88	4.60	13.48	14.27	65.88	62.23	13.7	15.0	30.7

Appendix Table C2 (Continued)

Horizon	Depth (cm)	pH		OM	Total N	Avai. P	Avai. K	Exchangeable bases				Sum bases	EA	CEC		BS		EC (sat.) dSm ⁻¹	SAR	ESP %
		H ₂ O	KCl					Ca	Mg	K	Na			Sum	NH ₄ OAc	Sum	NH ₄ OAc			
				(...g kg ⁻¹ ...)		(...mg kg ⁻¹ ...)		(.....)				cmol kg ⁻¹		(.....)		(.....%)				
<u>Pedon 7</u>	<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>																			
Apng1	0-20/35	7.0	8.7	2.00	0.80	3.7	26.9	3.51	3.03	0.06	9.37	13.24	4.32	17.56	6.54	75.40	202.80	29.6	79.2	143.30
Apng2	35-52/55	6.5	6.7	0.96	5.00	3.9	53.1	1.32	0.44	0.13	27.86	29.75	5.92	35.67	6.99	83.40	425.77	74.0	359.0	398.46
Btng1	55-76/81	7.0	7.7	0.53	2.60	0.0	29.9	1.79	0.52	0.07	8.66	11.04	8.32	19.36	14.21	57.02	77.37	11.3	96.3	60.5
Btng2	81-115/118	7.0	8.2	0.74	1.20	1.0	19.1	2.03	0.72	0.04	8.69	11.48	6.72	18.20	5.63	63.08	203.80	7.5	89.9	154.1
Btng3	118-130/137	7.0	8.0	0.87	0.50	0.1	19.8	2.06	1.09	0.05	12.86	16.06	6.72	22.78	13.19	70.50	121.80	3.2	126.6	97.5
Btng4	137-150/163	8.0	7.4	0.80	0.10	1.7	15.8	2.38	1.25	0.04	12.97	16.64	5.12	21.76	14.32	76.47	116.26	6.3	119.0	90.6
Btng5	163-190	8.0	7.4	0.78	0.40	1.1	14.8	2.14	1.22	0.03	13.00	16.39	5.92	22.31	14.52	73.46	113.04	5.2	124.2	89.5
<u>Pedon 8</u>	<i>Typic Natraqualf; fine-loamy, mixed, isohyperthermic</i>																			
Apng	0-20	6.0	7.1	14.11	10.10	7.2	97.0	6.46	0.87	0.24	26.95	34.52	10.74	45.26	10.71	76.27	322.50	58.8	119.5	251.60
Btng1	20-45/50	6.0	7.7	1.92	2.00	0.0	65.3	3.34	1.02	0.16	6.38	10.90	6.72	17.62	11.39	61.86	95.87	11.9	52.1	56.1
Btng2	50-65/70	6.0	8.0	0.48	1.40	7.3	71.3	4.39	1.12	0.82	9.46	15.79	5.12	20.91	8.90	75.51	177.60	7.7	68.4	106.29
Btng3	70-95/100	6.5	8.1	0.65	1.40	0.8	73.7	2.39	0.86	0.18	12.22	15.65	3.52	19.17	9.47	81.64	165.50	8.4	116.4	129.41
Btng4	100-112/1	6.5	8.0	0.36	1.40	0.7	66.3	1.94	0.75	0.17	11.78	14.64	6.72	21.36	10.71	68.54	129.70	14.4	123.7	109.97
Btng5	120-130/1	6.5	7.8	0.88	0.90	0.2	74.0	2.54	8.46	0.18	14.30	25.48	5.92	31.40	14.21	81.15	125.90	15.0	133.1	100.65
Btng6	138-160/1	6.5	7.6	0.61	0.80	4.1	97.9	2.29	0.91	0.25	17.00	20.45	6.72	27.17	25.71	75.27	9.60	19.9	163.8	66.1
2Cng1	170-172/1	6.5	8.3	1.16	2.00	0.0	43.8	2.12	0.36	0.11	9.28	11.87	5.12	16.99	10.37	69.86	114.60	23.8	98.6	89.5
2Cng2	175-200	7.5	8.4	0.00	2.00	0.0	114.3	16.35	1.02	0.29	19.02	36.68	5.12	41.80	18.49	87.75	198.50	6.4	75.1	102.86
<u>Pedon 9</u>	<i>Typic Natraqualf; fine, mixed, isohyperthermic</i>																			
Apng	0-13/15	8.0	7.5	11.74	11.80	1.7	98.7	10.52	4.16	0.25	4.56	19.49	4.32	23.81	20.30	81.86	96.10	17.2	21.6	22.4
Btng1	15-37/43	8.0	7.4	2.24	5.40	0.2	67.2	5.89	4.38	0.17	4.50	14.94	7.52	22.46	24.24	66.52	61.70	8.7	25.1	18.6
Btng2	43-72/73	8.0	7.8	2.48	3.40	0.8	78.2	15.10	6.68	0.20	6.07	28.05	3.52	31.57	38.90	88.85	72.10	8.8	22.6	15.6
Ckng1	73-96	8.0	7.7	2.18	3.40	0.0	76.3	24.98	6.11	0.19	6.62	37.90	4.32	42.22	34.84	89.77	108.80	9.4	20.1	19.0
Ckng2	96-123/12	8.0	7.8	2.11	2.90	0.0	89.1	27.52	6.40	0.22	6.20	40.34	4.32	44.66	31.01	90.33	130.40	9.5	17.9	19.9
Ckng3	126-190	8.0	7.8	1.26	2.00	0.2	88.4	26.20	5.49	0.22	5.47	37.38	5.12	42.50	33.49	87.95	111.79	10.3	16.4	16.4

Appendix Table C2 (Continued)

Horizon	Depth (cm)	pH		OM	Total N	Avai. P	Avai. K	Exchangeable bases				Sum bases	EA	CEC		BS		EC (sat.) dSm ⁻¹	SAR	ESP %
		H ₂ O	KCl					Ca	Mg	K	Na			Sum	NH ₄ OAc	Sum	NH ₄ OAc			
				(...g kg ⁻¹ ...)	(...mg kg ⁻¹ ...)	(...mg kg ⁻¹ ...)	(...mg kg ⁻¹ ...)	(.....)	(.....)	(.....)	(.....)	cmol kg ⁻¹	(.....)	(.....)	(.....)	(.....)	(.....%)	(.....)	(.....)	(.....)
Pedon 10 <i>Typic Natraqualf; loamy-skeletal, mixed, isohyperthermic</i>																				
Apng	0-12/15	6.3	6.2	7.70	0.09	5.0	7.0	3.28	0.49	0.02	5.08	8.87	3.00	11.87	1.75	74.73	506.86	218.0	33.9	290.5
Btng	15-32/36	7.1	6.1	4.60	0.13	0.7	17.2	7.80	1.39	0.04	6.02	15.25	2.10	17.35	9.86	87.90	154.67	11.3	18.9	61.1
Btng1	36-60	7.8	7.0	2.70	0.13	1.2	17.0	6.09	0.90	0.04	4.65	11.68	0.70	12.38	15.00	94.35	77.87	8.1	17.0	31.0
Btng2	60-85	8.1	7.1	1.30	0.10	4.7	16.9	5.50	1.14	0.04	5.93	12.61	8.30	20.91	16.75	60.31	75.28	7.1	17.6	35.4
Btng3	85-106	8.5	6.8	1.10	0.13	5.9	10.8	3.61	0.48	0.03	3.27	7.39	4.30	11.69	10.50	63.22	70.38	6.4	17.5	31.1
Btng4	106-125/13	8.6	7.0	1.00	0.03	6.8	16.9	5.02	1.24	0.04	124.17	130.47	2.00	132.47	14.38	98.49	907.30	8.9	16.9	863.8
BCng	130-156	8.1	6.9	1.20	0.03	16.9	22.3	5.60	1.76	0.06	122.27	129.69	5.30	134.99	19.34	96.07	670.58	8.4	17.3	632.3
Crng1	156-180	7.5	6.4	1.10	0.07	110.6	40.3	5.63	2.72	0.10	8.39	16.84	5.80	22.64	33.10	74.38	50.88	9.9	18.5	25.4
Crng2	182-203+	7.8	6.4	1.10	0.06	219.6	41.2	4.79	2.47	0.11	7.66	15.03	6.80	21.83	40.23	8.85	37.36	14.5	24.4	19.1
Pedon 11 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																				
Apng1	0-10	5.4	4.9	12.25	0.56	2.3	55.8	9.65	2.21	0.14	3.18	15.19	8.34	23.53	16.48	64.55	160.38	60.5	10.4	19.3
Apng2	10-20	5.5	4.7	7.86	0.44	1.1	52.8	9.25	1.76	0.14	4.21	15.36	9.20	24.56	20.09	62.55	103.74	11.3	5.4	21.0
Btng1	20-33	6.1	5.7	4.54	0.27	1.3	39.0	8.11	1.48	0.10	4.31	13.99	5.98	19.97	16.61	70.06	110.76	9.6	7.7	25.9
Btng2	33-48	6.6	5.8	3.27	0.22	1.3	27.3	7.47	1.22	0.07	4.25	13.00	3.13	16.13	13.82	80.62	118.69	8.6	7.9	30.8
Btng3	48-70	6.8	6.1	1.98	0.16	1.4	30.3	7.29	1.39	0.08	4.36	13.11	3.10	16.21	15.45	80.89	109.63	9.0	8.3	28.2
Btng4	70-88	7.0	6.1	1.43	0.11	0.9	31.4	7.69	1.31	0.08	3.68	12.76	3.09	15.85	14.69	80.51	112.13	7.2	8.4	25.0
2Btng5	88-114	7.1	6.1	0.71	0.09	0.2	30.4	6.66	1.22	0.08	3.86	11.82	2.45	14.28	13.09	82.81	113.39	8.2	9.1	29.5
2Btng6	114-135	7.2	6.1	0.53	0.06	0.2	31.8	6.39	1.17	0.08	3.19	10.84	3.08	13.91	12.86	77.87	112.50	14.2	12.6	24.8
2Btng7	135-156	7.2	6.1	0.70	0.07	0.4	23.4	4.95	0.96	0.06	2.96	8.94	2.42	11.36	9.42	78.67	126.63	12.4	8.7	31.5
2Btng8	156-190	7.2	6.2	0.18	0.05	0.2	26.7	3.99	0.80	0.07	2.11	6.96	2.13	9.09	7.41	76.60	140.41	16.2	10.3	28.5
Pedon 12 <i>Typic Natraqualf; very fine, kaolinitic, isohyperthermic</i>																				
Apng1	0-18	5.2	4.6	22.01	0.94	2.5	54.1	10.78	1.88	0.14	2.69	15.49	12.41	27.90	19.69	55.51	95.49	10.3	4.8	13.7
Apng2	18-30	4.9	4.1	15.54	0.70	0.4	47.5	9.99	1.80	0.12	1.85	13.76	13.57	27.33	21.74	50.35	79.79	8.7	5.1	8.5
Btng1	30-42	4.9	4.1	10.26	0.49	0.6	48.1	8.98	1.56	0.12	2.04	12.70	12.46	25.16	19.57	50.48	82.54	7.2	5.1	10.41
Btng1	42-53/64	5.3	4.6	8.23	0.47	0.2	57.1	13.19	2.10	0.15	4.24	19.68	12.01	31.69	25.89	62.10	90.83	7.1	5.6	16.4
Btng2	64-79	5.8	5.1	6.59	0.30	0.2	54.4	11.71	2.20	0.14	4.95	19.00	9.45	28.45	25.55	66.78	89.30	6.5	6.3	19.4
Btng3	79-100	6.0	5.3	5.29	0.26	0.4	43.4	11.51	1.90	0.11	5.34	18.85	8.18	27.03	22.72	69.74	96.25	7.3	7.0	23.5
Btng4	100-124	6.3	5.5	2.72	0.13	0.4	36.5	9.85	1.70	0.09	4.52	16.16	6.89	23.05	19.23	70.12	104.98	7.6	7.6	23.5

Appendix Table C2 (Continued)

Horizon	Depth (cm)	pH		OM (...g kg ⁻¹ ...)	Total N	Avai. P (mg kg ⁻¹ ...)	Avai. K	Exchangeable bases				Sum bases cmol kg ⁻¹	EA	CEC		BS		EC (sat.) dSm ⁻¹	SAR	ESP %
		H ₂ O	KCl					Ca	Mg	K	Na			Sum	NH ₄ OAc	Sum	NH ₄ OAc			
Btng5	124-151	6.6	5.7	0.90	0.16	0.2	32.5	9.70	1.62	0.08	5.33	16.73	4.97	21.70	19.59	77.09	105.72	6.4	7.5	27.2
2Btng6	151-176	6.7	5.7	0.53	0.11	0.3	33.7	8.06	1.41	0.09	4.24	13.79	3.71	17.50	15.10	78.81	112.76	8.6	8.1	28.1
2Btng7	176-200	6.8	5.9	0.35	0.10	0.4	21.9	4.87	1.02	0.06	2.44	8.39	2.46	10.84	9.56	77.35	123.10	13.2	9.3	25.5
<i>Pedon 13 Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																				
Apg	0-11	5.1	4.5	21.54	0.92	9.8	83.1	11.64	2.32	0.21	1.97	16.14	10.06	26.20	21.49	61.60	95.92	13.4	4.2	9.2
Btg1	11-32	5.4	4.4	9.53	0.45	0.9	52.8	12.34	2.16	0.14	2.45	17.09	10.52	27.61	23.82	61.90	81.79	5.5	3.8	10.3
Btg2	32-56	5.9	5.2	6.70	0.34	0.9	34.1	12.00	1.82	0.09	2.14	16.05	6.60	22.65	21.23	70.86	86.55	5.3	4.3	10.08
Btng1	56-65/85	6.3	5.7	4.15	0.26	0.9	54.9	12.82	1.95	0.14	3.12	18.03	2.81	20.84	19.94	86.52	102.80	4.7	4.5	15.6
Btng2	85-110	6.5	5.8	2.71	0.16	0.9	35.2	13.07	1.93	0.09	3.47	18.56	2.81	21.37	20.72	86.85	103.73	5.0	5.0	16.7
Btng3	110-124	6.4	5.8	1.27	0.15	0.5	38.1	12.08	2.05	0.10	4.11	18.34	3.15	21.49	20.85	85.34	105.83	5.8	5.2	19.7
2Btng4	124-152	6.7	5.8	0.93	0.16	0.2	59.7	18.32	3.15	0.15	6.18	27.80	5.80	33.60	31.14	82.74	108.07	7.5	5.8	19.8
2Btng5	152-180+	6.7	6.0	0.55	0.16	0.2	50.2	13.91	2.42	0.13	5.25	21.71	4.12	25.83	24.44	84.05	109.77	8.4	6.2	21.5
<i>Pedon 14 Typic Endoaqualf; fine, kaolinitic, isohyperthermic</i>																				
Apg1	0-10	5.4	4.8	20.22	0.93	9.0	61.8	6.92	1.40	0.16	0.8	9.28	6.72	16.00	12.84	58.00	101.18	11.1	4.0	6.3
Apg2	10-22	5.7	4.9	9.75	0.52	1.4	41.8	6.84	1.28	0.11	1.38	9.61	6.48	16.09	12.7	59.73	84.03	3.4	3.1	10.9
Btg1	22-38	5.3	4.7	7.55	0.45	0.5	42.5	8.55	1.49	0.11	1.34	11.49	7.72	19.21	16.44	59.81	77.62	3.6	3.0	8.2
Btg2	38-60	5.3	4.6	6.69	0.37	0.7	39.7	9.68	1.65	0.10	1.19	12.62	8.18	20.80	19.17	60.67	73.33	3.7	3.1	6.2
Btg3	60-83	5.6	5.1	3.80	0.22	0.7	32.5	11.6	1.76	0.08	1.60	15.04	6.85	21.89	18.99	68.71	87.39	3.9	3.3	8.4
Btg4	83-102	6.3	5.5	2.34	0.16	0.7	29.2	13.3	1.91	0.07	2.34	17.62	4.93	22.55	19.01	78.14	100.32	3.7	3.4	12.3
2Btg5	102-121	6.6	5.9	1.78	0.13	0.3	24.7	11.2	1.67	0.06	1.62	14.55	3.09	17.64	16.46	82.48	96.49	3.0	2.9	9.9
2Btg6	121-140	6.7	6.1	0.71	0.09	0.2	25.6	9.23	1.45	0.07	1.26	12.01	1.84	13.85	13.5	86.71	98.89	4.1	3.2	9.3
2Btg7	140-162	6.8	6.2	0.35	0.06	0.2	24.1	7.45	1.33	0.06	0.97	9.81	1.21	11.02	11.77	89.02	95.51	5.9	3.9	8.3
2Btg8	162-190	6.9	6.2	0.17	0.05	0.2	22.9	6.15	1.20	0.06	0.99	8.40	0.91	9.13	14.09	90.23	71.34	5.5	3.6	7.0
<i>Pedon 15 Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																				
Apg	0-15	4.9	3.7	6.53	0.27	6.2	8.9	2.52	0.05	0.02	0.14	2.73	5.68	8.41	1.65	32.47	172.61	0.5	2.4	8.2
Bcg	15-50	7.2	6.3	1.58	0.09	1.1	20.6	9.35	1.87	0.05	1.94	13.22	6.69	19.91	20.10	66.38	68.45	0.7	6.0	9.7
Btg1	50-70	7.5	6.3	1.23	0.03	0.7	21.3	9.83	1.79	0.05	2.14	13.82	6.37	20.19	29.47	68.45	49.18	0.9	5.8	7.3
Btg2	70-90	7.6	6.3	1.05	0.05	0.4	20.4	8.78	1.60	0.05	1.85	12.28	5.78	18.06	18.29	67.99	70.88	1.1	4.8	10.1
Btg3	90-110	7.4	6.1	0.87	0.07	0.4	19.8	9.68	1.38	0.05	1.80	12.91	5.76	18.66	27.83	69.15	48.89	1.2	4.5	6.5
2Btg4	110-130	7.4	6.4	1.04	0.03	0.4	16.1	9.27	1.16	0.04	1.38	11.86	5.44	17.29	10.02	68.56	126.03	1.5	4.1	13.8

Appendix Table C2 (Continued)

Horizon	Depth (cm)	pH		OM	Total N	Avai. P	Avai. K	Exchangeable bases				Sum bases	EA	CEC		BS		EC (sat.) dSm ⁻¹	SAR	ESP %
		H ₂ O	KCl					Ca	Mg	K	Na			Sum	NH ₄ OAc	Sum	NH ₄ OAc %			
				(...g kg ⁻¹ ...)		(...mg kg ⁻¹ ...)		(.....cmol kg ⁻¹)												
2Btng1	130-153	7.5	4.4	1.04	0.03	0.4	16.7	7.01	0.96	0.04	1.52	9.52	5.45	14.97	9.83	63.60	104.73	1.7	5.0	15.5
2Btg5	153-182	7.4	6.4	1.04	0.05	0.4	18.2	6.53	0.93	0.05	1.43	8.94	5.74	14.68	15.06	60.89	65.32	2.5	6.4	9.5
2Btng2	182-200	7.3	6.3	0.87	0.03	0.4	19.7	7.90	0.88	0.05	1.32	10.15	5.77	15.93	7.49	63.74	150.30	2.4	5.9	17.6
Pedon 16 <i>Aeric Kandiaqualf; fine-loamy, mixed, isohyperthermic</i>																				
Apng	0-18	7.5	7.1	13.59	0.40	9.5	47.0	9.60	2.45	0.13	1.81	13.99	1.57	15.56	14.10	89.91	99.26	9.6	6.4	12.9
Btng1	18-36	7.4	6.7	2.50	0.13	2.2	31.0	7.96	2.50	0.10	1.23	11.79	1.33	13.12	14.00	89.86	84.25	4.9	4.7	8.8
Btng2	36-63	7.5	6.7	1.14	0.08	1.3	31.5	9.03	3.50	0.09	1.08	13.70	2.26	15.96	15.45	85.84	85.73	5.2	4.2	7.0
Btng3	63-101	7.7	7.1	1.98	0.08	1.8	28.0	9.84	3.50	0.11	1.03	14.48	2.26	16.74	15.85	86.50	91.36	4.1	3.8	6.5
Btkg	101-123	7.9	7.2	1.01	0.50	2.2	31.0	12.22	3.50	0.09	0.94	16.75	1.95	18.70	16.20	89.57	103.40	3.7	4.1	5.8
BCkg	123-135	8.0	7.3	0.53	0.05	0.2	21.5	12.69	3.30	0.07	0.89	16.95	1.49	18.44	14.35	91.92	118.01	3.3	4.1	6.2
Ckg1	135-160	8.1	7.5	0.68	0.04	0.3	14.0	10.26	2.50	0.06	0.78	13.60	1.03	14.63	9.20	92.96	147.72	3.4	3.9	8.4
Ckg2	160-195	8.1	7.4	0.89	0.05	0.3	16.5	9.85	2.70	0.05	0.83	13.43	1.18	14.61	8.65	91.92	155.26	3.1	4.3	9.7
Pedon 17 <i>Typic Natraqualf; sandy, silicious, subactive, isohyperthermic</i>																				
Apng	0-11	8.3	8.1	2.58	0.05	1.3	20.8	0.29	0.15	0.05	0.83	1.32	6.31	7.64	0.90	17.33	825.97	37.7	45.2	91.9
Bng1	11-30	8.1	7.5	0.69	0.02	1.1	5.7	0.11	0.08	0.01	0.47	0.68	6.84	7.52	0.45	9.00	404.49	7.5	16.8	105.4
Bng2	30-47	7.7	7.3	0.34	0.01	1.1	6.5	0.13	0.08	0.02	0.26	0.49	7.76	8.26	0.40	5.95	547.25	11.3	19.2	65.0
Btng1	47-69	8.0	7.5	0.34	0.02	1.8	11.9	0.12	0.13	0.03	0.17	0.46	7.21	7.66	0.50	5.98	389.77	9.6	19.6	35.0
Btng2	69-95	8.5	7.2	0.52	0.05	1.8	49.1	0.99	0.60	0.13	2.05	3.76	7.25	11.02	3.19	34.16	188.68	9.7	22.0	64.1
Btng3	95-110	8.4	7.0	0.17	0.02	1.8	59.2	0.90	0.87	0.15	3.29	5.22	6.94	12.15	5.38	42.92	147.98	15.0	25.6	61.1
Btng4	110-130	8.3	7.1	0.17	0.02	1.8	59.9	1.33	0.84	0.15	3.01	5.33	6.97	12.30	5.16	43.36	165.89	12.1	20.5	58.3
Btng5	130-153	8.1	7.1	0.35	0.01	1.1	59.7	1.40	0.87	0.15	2.61	5.03	8.16	13.19	6.51	38.13	121.69	8.7	18.5	40.1
2Btng6	153-178	8.1	6.9	0.18	0.02	1.4	100.4	1.98	1.24	0.26	4.36	7.84	7.58	15.42	8.50	50.84	124.70	10.1	16.6	51.3
2Btng7	178-200+	7.8	6.8	0.18	0.02	33.8	146.9	2.40	1.48	0.38	4.98	9.24	7.68	16.92	10.39	54.61	118.82	9.0	21.8	47.9
Pedon 18 <i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																				
Apng	0-20/23	6.5	4.3	7.67	7.70	0.4	64.1	2.90	0.87	0.16	5.13	9.06	9.36	18.42	18.60	49.19	48.76	15.3	45.0	27.6
Btng1	23-35/42	4.5	3.8	1.40	8.80	0.1	46.1	4.05	1.22	0.11	8.30	13.68	8.56	22.24	11.59	61.51	118.30	6.9	61.7	71.7
Btng2	42-62/72	5.5	3.7	0.71	5.00	0.0	42.6	3.77	1.27	0.10	7.75	12.89	7.76	20.65	10.71	62.42	124.76	9.2	59.1	72.4
Btng3	72-98/118	6.0	3.8	0.68	4.50	0.3	50.8	4.92	1.65	0.13	6.68	13.38	7.76	21.14	27.63	63.29	48.50	9.9	44.6	27.2
Btng4	118-122/137	5.5	4.0	1.16	8.30	0.2	57.9	5.64	1.95	0.14	8.95	16.68	10.16	26.84	29.32	62.15	56.94	11.9	55.8	30.5
Btng5	137-162/168	5.5	3.9	0.94	9.20	0.2	62.8	5.87	2.03	0.16	26.81	34.87	10.16	45.03	20.89	77.44	167.48	8.6	162.4	128.3
Btng6	168-193	5.5	3.8	1.35	8.10	1.4	71.4	7.18	2.27	0.18	12.41	22.04	7.76	29.80	41.50	73.96	53.17	12.1	68.9	29.9

Appendix Table C2 (Continued)

Horizon	Depth	pH		OM	Total	Avai.	Avai.	Exchangeable bases				Sum	EA	CEC		BS		EC	SAR	ESP
		H ₂ O	KCl					N	P	K	Ca			Mg	K	Na	bases			
	(cm)			(.....g kg ⁻¹ ...)		(...mg kg ⁻¹ ...)		(.....cmol kg ⁻¹)								%		dSm ⁻¹		%
Pedon 19	<i>Typic Natraqualf; coarse-loamy, mixed, isohyperthermic</i>																			
Apng	0-13/16	5.0	4.6	3.60	2.20	2.2	39.6	0.36	0.08	0.10	3.82	4.36	4.56	8.92	18.60	48.88	23.50	14.9	97.1	20.6
Bng1	13-35/37	5.5	6.4	0.97	1.60	0.2	37.8	2.42	0.13	0.09	3.24	5.88	3.76	9.64	13.42	61.00	44.07	7.1	33.4	24.2
Bng2	37-68	5.5	5.9	0.87	1.50	0.4	18.6	0.49	0.05	0.04	2.90	3.48	2.96	6.44	13.06	54.04	27.63	4.3	64.9	24.1
Btng1	68-86	5.0	4.6	0.90	0.10	1.3	35.1	0.45	0.10	0.09	4.16	4.80	6.16	10.96	10.71	43.80	44.90	7.9	94.3	38.9
Btng2	86-100	6.0	4.3	1.18	1.50	0.0	35.9	0.42	0.10	0.09	5.29	5.90	3.76	9.66	15.90	61.08	37.24	12.6	122.7	33.2
Btng3	100-108/120	5.5	4.5	0.87	1.10	0.1	39.2	0.48	0.11	0.10	5.44	6.13	5.36	11.49	32.14	53.35	19.16	17.2	118.7	16.9
Btng4	120-125/131	5.5	4.9	1.11	1.10	0.0	53.2	0.48	0.11	0.11	9.22	9.92	4.56	14.48	12.74	68.51	78.06	20.2	200.2	74.4
Cng	131-160	6.5	7.2	1.70	0.50	0.3	44.2	0.41	0.08	0.11	7.71	8.31	6.16	14.47	26.61	57.43	31.30	28.7	182.0	29.0
Pedon 20	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																			
Apg	0-15/23	5.2	3.6	6.54	0.33	9.9	12.0	0.76	0.09	0.03	0.04	0.92	5.67	6.58	2.16	13.92	45.66	0.4	1.8	1.8
Bcg	23-46	7.0	5.6	2.28	0.16	1.2	22.0	8.30	1.56	0.06	0.90	10.81	6.38	17.19	26.06	62.91	42.35	0.4	2.9	3.5
Btg1	46-65	7.6	6.1	1.05	0.11	0.4	21.1	10.71	1.75	0.05	1.74	14.26	5.81	20.07	12.25	71.06	122.11	2.9	4.2	14.2
Btg2	65-88	6.4	6.3	0.7	0.02	0.3	18.6	8.97	1.32	0.05	1.68	12.02	5.19	17.21	28.07	69.85	46.25	2.0	4.1	6.0
Btg3	88-113	7.4	6.4	0.52	0.07	0.1	14.5	8.35	1.04	0.04	1.46	10.89	4.85	15.74	26.54	69.20	45.58	2.6	4.7	5.5
2Btng1	113-140	6.9	6.3	0.7	0.03	0.1	13.0	3.81	0.76	0.03	1.20	5.79	4.52	10.31	7.18	56.17	100.30	3.4	5.3	16.7
2Btng2	140-172	6.7	5.9	0.52	0.10	0.3	13.2	3.39	0.70	0.03	0.97	5.09	4.21	9.30	6.52	54.72	100.64	3.6	5.1	14.8
2Btng3	172-205+	6.8	6.1	0.35	0.04	0.1	18.9	4.28	0.78	0.05	1.45	6.56	5.13	11.70	10.22	56.11	77.94	2.8	5.4	14.2
Pedon 21	<i>Typic Natraqualf; fine, kaolinitic, isohyperthermic</i>																			
Apg	0-19/20	4.9	3.7	7.22	0.35	6.0	4.0	0.26	0.02	0.01	0.01	0.30	4.77	5.07	5.06	5.92	7.40	0.3	2.0	0.1
Apng	20-27/32	6.1	4.2	1.72	0.08	1.4	1.6	0.21	0.01	0.00	0.16	0.38	3.57	3.95	0.65	9.62	64.60	0.4	3.1	25.0
Bcg	32-54/63	8.0	6.2	1.74	0.16	1.1	13.9	8.29	0.75	0.04	1.02	10.10	5.15	15.25	9.65	66.23	106.82	0.4	3.0	10.6
Btg1	63-82/87	7.4	6.0	0.70	0.09	0.6	18.8	11.25	1.17	0.05	1.63	14.10	5.19	19.29	26.50	73.09	55.08	0.6	4.9	6.2
Btg2	87-111/114	7.5	6.2	0.88	0.09	0.1	16.6	9.28	1.00	0.04	1.62	11.94	4.58	16.52	24.57	72.28	50.83	0.8	5.3	6.6
2Btg3	114-137	7.7	6.4	0.87	0.09	0.1	15.1	8.82	8.37	0.04	1.59	18.82	4.89	23.71	18.50	79.38	104.19	1.3	6.9	8.6
2Btg4	137-155	7.3	6.1	0.52	0.09	0.1	14.4	7.26	0.74	0.04	1.56	9.60	5.18	14.78	12.93	64.95	78.08	1.0	4.3	12.1
2Btng1	155-183	7.2	6.1	0.35	0.05	0.1	13.0	5.14	0.60	0.03	1.32	7.09	5.14	12.23	7.15	57.97	106.53	1.4	5.8	18.5
2Btng2	183-207+	7.0	6.5	0.70	0.07	0.1	14.8	5.09	0.60	0.04	1.44	7.17	5.13	12.30	7.14	58.29	108.83	1.4	4.0	20.2

Appendix Table C3 Linear correlation coefficients for relationship between aggregate stability and properties of kaolinitic soils (marked
cored correlations are significant at $p < 0.05$, $N = 56$).

	AS	EC	SAR	ESP	pH (H ₂ O)	pH (KCl)	OM	Total N	Avai. P	Avai. K	Ext. Ca	Ext. Mg	Ext. K	Ext. Na	Sum base	EA	CEC (Sum)	CEC	BS (Sum)	BS	Sand
AS	1.00																				
EC	0.07	1.00																			
SAR	-0.33	0.56	1.00																		
ESP	-0.22	0.33	0.80	1.00																	
pH (H ₂ O)	-0.84	-0.19	0.35	0.31	1.00																
pH (KCl)	-0.82	-0.15	0.32	0.33	0.95	1.00															
OM	0.66	0.32	-0.20	-0.28	-0.81	-0.81	1.00														
Total N	0.70	0.31	-0.20	-0.25	-0.83	-0.83	0.99	1.00													
Avai.P	0.30	0.30	-0.05	-0.09	-0.38	-0.35	0.67	0.65	1.00												
Avai.K	0.75	0.36	-0.05	-0.01	-0.75	-0.73	0.75	0.79	0.58	1.00											
Ext. Ca	0.57	-0.04	-0.33	-0.24	-0.34	-0.36	0.28	0.33	0.16	0.61	1.00										
Ext. Mg	0.15	0.05	0.03	-0.13	0.01	-0.04	0.13	0.15	0.09	0.21	0.39	1.00									
Ext. K	0.75	0.35	-0.04	0.00	-0.74	-0.72	0.74	0.78	0.57	1.00	0.60	0.21	1.00	0.44							
Ext. Na	0.19	0.24	0.51	0.70	0.00	0.02	-0.04	0.02	-0.01	0.43	0.43	0.18	0.44	1.00							
Sum base	0.50	0.06	-0.06	0.03	-0.24	-0.26	0.22	0.27	0.14	0.62	0.93	0.57	0.62	0.66	1.00						
EA	0.66	0.08	-0.31	-0.38	-0.83	-0.89	0.81	0.81	0.30	0.61	0.30	0.11	0.60	-0.05	0.22	1.00					
CEC (Sum)	0.73	0.09	-0.21	-0.19	-0.64	-0.68	0.61	0.65	0.27	0.78	0.83	0.47	0.78	0.45	0.84	0.72	1.00				
CEC	0.51	-0.09	-0.28	-0.37	-0.38	-0.40	0.32	0.35	0.13	0.53	0.81	0.34	0.53	0.35	0.76	0.44	0.79	1.00			
BS (Sum)	-0.30	0.01	0.27	0.35	0.59	0.64	-0.57	-0.55	-0.18	-0.19	0.20	0.18	-0.18	0.37	0.30	-0.82	-0.24	-0.01	1.00		
BS	-0.14	0.60	0.66	0.76	0.23	0.25	-0.11	-0.09	0.08	0.08	-0.14	0.12	0.08	0.43	0.07	-0.35	-0.14	-0.50	0.35	1.00	
Sand	-0.56	0.22	0.49	0.33	0.51	0.50	-0.38	-0.40	-0.13	-0.51	-0.74	-0.25	-0.50	-0.27	-0.66	-0.57	-0.79	-0.68	0.30	0.35	1.00
Silt	-0.32	-0.31	-0.42	-0.43	0.08	0.09	-0.03	-0.09	-0.04	-0.38	-0.22	-0.03	-0.39	-0.50	-0.32	0.09	-0.18	-0.17	-0.36	-0.35	-0.26
Clay	0.72	-0.07	-0.29	-0.12	-0.55	-0.55	0.39	0.45	0.15	0.70	0.85	0.26	0.70	0.52	0.83	0.53	0.89	0.77	-0.13	-0.18	-0.88

AS= Aggregate stability (%), EC= Electrical conductivity (dS m⁻¹), ESP= Exchangeable sodium percentage (%), SAR= Sodium adsorption ratio, OM= Organic matter (g kg⁻¹), Avai.= available, Ext.= Extractable bases (cmol kg⁻¹), EA= Extractable acidity (cmol kg⁻¹), CEC= Cation exchange capacity by NH₄OAc, BS= Bases saturation percentage

Appendix Table C4 Environmental factors of soils for the multiple regression analysis of the relationships between salt content of the soil profiles and environmental factors.

Pedon	Log [Salt content, ton ha ⁻¹]	Log [Rainfall, mm y ⁻¹]	^A Land form	^B Parent material	^C Rock type	Slope (%)	^D Land use	Sand (%)	Silt (%)	Clay (%)
P1	3.23	2.97	1	1	1	2	1	55	24	22
P2	3.31	2.98	2	3	2	2	1	49	18	33
P3	3.26	2.98	2	1	2	2	1	10	17	73
P4	2.99	3.01	1	3	2	1	2	70	16	15
P5	3.49	2.96	1	3	1	1	2	49	28	23
P6	3.22	2.96	1	1	1	3	2	32	36	32
P7	3.17	2.97	1	1	1	2	1	64	15	20
P8	3.16	2.99	1	3	1	2	3	40	33	27
P9	2.85	2.92	1	1	2	1	2	39	21	41
P10	3.09	3.00	1	2	2	2	2	55	20	25
P11	3.12	2.99	3	3	1	1	2	45	19	37
P12	2.57	3.01	1	1	1	2	3	46	21	32
P13	3.09	3.00	2	3	2	2	2	78	9	13
P14	2.87	3.05	1	1	1	2	3	18	38	44
P15	3.12	3.02	1	1	1	3	3	67	15	18
P16	2.38	3.09	2	3	2	2	3	34	32	34

^A 1= Low terrace, 2= Erosional terrace, 3= Flood plain

^B 1= Transported material, 2= Residuum, 3= Transported material over residuum

^C 1= Quaternary Fluvial Deposits (Qa), 2= Maharashtra Formation (Ktms)

^D 1= Left idle/ grasses, 2= paddy/ left idle, 3= paddy

Appendix Table C5 Multiple regression results for the relationships between salt content in the soil profiles and environmental factors.

Step	Equation	R ²
1	$\log [\text{Salt content}] = 16.67 - 4.55 \log [\text{Rainfall}]$	0.42
2	$\log [\text{Salt content}] = 12.82 - 3.18 \log [\text{Rainfall}] - 0.12[\text{Landuse}]$	0.49
3	$\log [\text{Salt content}] = 10.91 - 2.44 \log [\text{Rainfall}] - 0.17[\text{Landuse}] - 0.15[\text{Rock Type}]$	0.56
4	$\log [\text{Salt content}] = 12 - 2.844 \log [\text{Rainfall}] - 0.17[\text{Landuse}] - 0.21[\text{Rock Type}] + 0.05[\text{Parent material}]$	0.66
5	$\log [\text{Salt content}] = 14.39 - 3.77 \log [\text{Rainfall}] - 0.17[\text{Landuse}] - 0.19[\text{Rock Type}] + 0.14[\text{Parent material}] + 0.15[\text{Slope}]$	0.73

Appendix Table C6 Soil pH (soil: water=1:1).

Rating	Range
Ultra acid	<3.5
Extremely acid	3.5-4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	>9.0

Appendix Table C7 Organic matter content (%organic carbon x 1.724).

Rating	Range (g kg ⁻¹)
Very low	<5
Low	5-10
Moderately low	10-15
Medium	15-25
Moderately high	25-35
High	35-45
Very high	>45

Appendix Table C8 Total nitrogen.

Rating	Range (g kg ⁻¹)
Very low	<0.25
Low	0.50-0.75
Medium	0.75-1.25
High	1.25-1.75
Very high	>2.25

Appendix Table C9 Available phosphorus (Bray II).

Rating	Range (mg kg ⁻¹)
Very low	<3
Low	3-6
Moderately low	6-10
Medium	10-15
Moderately high	15-25
High	25-45
Very high	>45

Appendix Table C10 Available potassium.

Rating	Range (mg kg ⁻¹)
Very low	<30
Low	30-60
Medium	60-90
High	90-120
Very high	>120

Appendix Table C11 Cation exchange capacity (CEC).

Rating	Range (cmol kg ⁻¹)
Very low	<3
Low	3-5
Moderately low	5-10
Medium	10-15
Moderately high	15-20
High	20-30
Very high	>30

Appendix Table C12 Base saturation percentage (PSB).

Rating	Range (%)
Low	<35
Medium	35-75
High	>75

Appendix Table C13 Extractable acidity (EA).

Rating	Range (cmol kg ⁻¹)
Very low	<1.0
Low	1.0-2.0
Medium	2.0-5.0
Moderately high	5.0-10.0
High	10.0-20.0
Very high	>20.0

Appendix Table C14 Bulk density (BD).

Rating	Range (Mg m ⁻³)
Low	<1.2
Moderately low	1.2-1.4
Medium	1.4-1.6
Moderately high	1.6-1.8
High	1.8-2.0
Very high	>2.0

Source: Nongkran (1986)

Appendix Table C15 Hydraulic conductivity (Ksat).

Rating	Range (cm hr ⁻¹)
Very slow	<0.125
Slow	0.125-0.50
Moderately slow	0.50-2.00
Moderate	2.00-6.25
Moderately rapid	6.25-12.50
Rapid	12.50-25.00
Very rapid	>25.00

Source: O'Neal (1952)

Appendix Table C16 Chemical criteria for salt affected soil classification.

Soil	pH	Electrical conductivity (EC) (dS m ⁻¹)	Sodium adsorption ratio (SAR)	Exchangeable sodium percentage (ESP) (%)
Normal	6.7-7.2	<4	<13	<15
Saline	<8.5	>4	<13	<15
Sodic	≥8.5	<4	>13	>15
Saline-Sodic	<8.5	>4	>13	>15

Source: Soil Survey Staff (2006)

Appendix Table C17 X-ray diffraction spacings obtained from (001) planes of layer-silicated species as related to sample treatment.

Diffraction spacing (nm)	Mineral (or minerals) Indicated
	<u>Mg-saturated, air-dried</u>
1.4-1.5	Smectite, vermiculite, chlorite
0.99-1.01	Mica (illite), halloysite
0.72-0.75	Metahalloysite
0.715	Kaolinite, chlorite (2nd-order maximum)
	<u>Mg-saturated, glycerol-solvated</u>
1.77-1.80	Smectite
1.4-1.5	Vermiculite, chlorite
1.08	Halloysite
0.99-1.01	Mica (illite)
0.72-0.75	Metahalloysite
0.75	Kaolinite, chlorite (2nd-order maximum)
	<u>K-saturated, air-dried</u>
1.4-1.5	Chlorite, vermiculite (with interlayer aluminium)
1.24-1.28	Smectite
0.99-1.01	Mica (illite), halloysite, vermiculite (contracted)
0.72-0.75	Metahalloysite
0.715	Kaolinite, chlorite (2nd-order maximum)
	<u>K-saturated, heated (550 °C)</u>
1.4	Chlorite
0.99-1.01	Mica, vermiculite (contracted), smectite (contracted)
0.715	Chlorite (2nd-order maximum)

Source: Whittig (1965)

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