VARIABILITY OF NATURAL SOIL SYSTEMS AS AFFECTED BY SALINITY LEVELS IN THAILAND

INTRODUCTION

Salt affected soil is a serious problem throughout the world and its area is getting larger. The salt affected soils are most often in areas with precipitation-to-evaporation ratios of 0.75 or less, and in low, flat areas with a high water table that may be subject to seepage from higher elevation. Areas where salt affected soils are found are mostly arid and semi-arid. They have salt accumulated in surface soils because there is insufficient water to leach salts from the upper layers (Brady and Weil, 2002). The soil surface may be bare because the high salt content inhibits the growth and yield of plants (Harris, 1960).

The salt in soils are primarily chlorides and sulfates of sodium, calcium, magnesium and potassium. They may be formed during the weathering of rock and minerals or deposited on the soils through rainfall and irrigation (Zoon, 1986; Brady and Weil, 2002). This is considered to be primary or natural salt accumulation. Salt accumulation may be regarded as secondary and associated with soil irrigation by mineralized river or groundwater when the drainage of soil is insufficient or zero, the salts in such water concentrate in soil and give rise to secondary salinization. The composition of salts, both for primary and secondary soil salinization, reflects their origin, as well as changes in hydrochemical regimes regulated by the zonal and local geomorphological, hydrogeological and management conditions (Zoon, 1986).

Salinity sometimes occurs naturally, usually at low points in the landscape, or in the down-basin extremes of catchments where regional groundwater flow systems may terminate in natural groundwater discharge zones (Abrol *et al.,* 1988; Commonwealth of Australia, 2001). Secondary salinity is common in dryland agricultural areas across southern Australia, and is reported in parts of the United State, Canada, Thailand and many other regions (Salama *et al.*, 1999a, b). In most instances dryland salinity is caused by saline groundwater seeping to the surface of the land. It impacts on soil quality and water resources negatively, depleting their utility and environmental value. Salinity is usually evident after water tables reach within 1.5 or 2.0 meters of the surface when shallow saline groundwater, drawn up by capillary action is further concentrated by evaporation (Abrol *et al.,* 1988; Commonwealth of Australia, 2001).

Soil salinity has several different forms, depending on how much salt accumulates in the soil. This in turn depends on the salinity of discharging groundwater, the climate and the texture of the affected soils (Commonwealth of Australia, 2001). In some arid regions where very saline groundwater discharges soil salinity is stark and extreme. In contrast, less saline groundwater discharge in more humid regions may cause dryland salinity that is much less obvious to the untrained eye.

In Thailand, the areas of salt affected soils are increasing. The soils mostly occur in three major locations, the Northeast Plateau basin, the Central Plain and the Coastal areas. Each location of salt affected soils is governed by different environment and soil forming factors. The environments and soil forming factors reflect on variable properties of salt affected soils, so the characteristics and classification of salt affected soils in Thailand are different (Takai *et al.*, 1987; Arunin, 1992).

Salt affected soil is a serious problem in Thailand, particularly in Northeast Plateau basin where salt bearing rocks are common (Department of Mineral Resources, 1982). The distribution and development of salt affected soils depend on three main factors: (1) natural soil forming processes, (2) man-made environments and (3) potential salinization of soils (Takai *et al.,* 1987; Arunin, 1992). Most of salt affected soils are being used for economic crop production especially for lowland rice cultivation. Salts affect soil and have a negative impact on the growth and yield of plants. The accumulation of salt reduces soil productivity. Salt affected soils need intensive management for both soil and plant to overcome the negative impacts of the salts and to prevent the problem from becoming worse. Management strategies needed for salt affected soil need to address the causes and mechanisms of the pedogenic processes (Takai *et al.,* 1987; Arunin, 1992; Yuvaniyama *et al.,* 1996). Studies on salt affected soils will help in formulating appropriate amending and preventive management practices.

This study aims at finding salt induced properties and characteristics of soils and differentiating criteria for pedogenic environments that induce salt effect into none salt affected natural soil systems under tropical savanna climate.

Hypothesis

The morphology, physics, chemistry and mineralogy of salt affected soil reflect variability of natural soil systems due to difference of salinity levels. Salts in soil control the change of soil properties

Objectives

1. To elucidate pedogenic conditions within salt affected soils in Thailand based on morphology, physical, chemical, mineralogical and micromorphological characteristics of the soils.

2. To establish relationships between properties of salt affected soil and salinity levels.

3. To compare soil characteristics between salt affected soils and non-salt affected soils occurring in adjacent areas.

LITERATURE REVIEW

Definition and Nature of Salt Affected Soils

Salt affected soils are soils that contain considerable amounts of soluble salt affecting the growth of plants. High soluble salt concentration in soil inhibits normal growth and yield of plants. Salt affected soils are classified into three groups: saline, sodic and saline-sodic soils. The principal criteria used to classify them are: salinity of soil saturation extract as determined by the electrical conductivity (EC) at 25^{o}C, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and the pH of their saturation extract (U.S. Salinity Laboratory Staff, 1954; Ghassemi *et al.*, 1995; FAO, 2000; Brady and Weil, 2002).

Saline Soil

Saline soils have electrical conductivity (EC) of a saturation extract of more than 4 dSm^{-1} or 2 dSm^{-1}. Their exchangeable sodium percentage (ESP) is less than 15, sodium adsorption ratio (SAR) is less than 13 and the pH value is usually less than 8.5. Salts are commonly brought to the soil surface by evaporating water, creating a white crust, which accounts for the name white alkali or Solonchak soils (Sys, 1980; Abrol *et al*, 1988; Soil Survey Division Staff, 1993; Ghassemi *et al.*, 1995; Singer and Munns, 1996).

Saline-Sodic Soil

Saline-sodic soils have electrical conductivity (EC) value of a saturation extract of the soil solution of more than 4 dSm^{-1}, ESP is greater than 15, SAR is greater than 13 and pH in saturation extract is 8.5 or less. The soluble salt of saline sodic soils is pushed down from surface part to the bottom of B horizon or into the C horizon, which accounts for the name black alkali or Solonnetz (U.S. Salinity Laboratory Staff, 1954; Ghassemi *et al.*, 1995; Brady and Weil, 2002).

Sodic Soil

Sodic soils have an electrical conductivity (EC) of the saturation extract less than 4 dSm^{-1}. Their ESP levels are above 15, SAR levels are above 13 and pH values exceed 8.5, rising to 10 or higher in some soils (Ghassemi *et al.,* 1995; Brady and Weil, 2002).

Classifications of Salt Affected Soils

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

Natric Horizon

The natric (modified from natrium, sodium; implying the presence of sodium) horizon is a special kind of argillic horizon. The dispersive properties of sodium accelerate clay illuviation. Research has showed that natric horizon formed in Holocene-age soil, even in arid or semiarid environments. The effect of sodium on dispersion of clay and on the formation of a B horizon of illuvial clay has long been recognized.

Salic Horizon

A salic horizon is a horizon of accumulation of salts that are more soluble than gypsum in cold water. A common salt is halite, the crystalline form of sodium chloride. In some areas highly soluble sulfates may also accumulate with the crystalline forms, such as thernadite, hexahydrite, epsomite and mirabilite. Two of the commonly occurring bicarbonates are trona and natron.

Salt Induced Soil Properties

The chemistry and concentration of soluble salt determined the properties and characteristics of salt affected soils (Haluschak, 2000). Apart from high salt content, salt affected soils show a considerable diversity in their hydrological, physical and chemical properties. Salt affected soils may be sodium dominated, calcium dominated or magnesium dominated with a consequent tendency towards structural degradation. Salts which are present in the soil solution precipitate at the surface in various forms such as white efflorescence, salt crusts, non-aggregated brown powder, black salt deposits or evaporative salt crystals (FAO, 2000).

The accumulation of salt in the soil profile, and the effects of Na^+ accumulation result in the occurrence of a natric or salic horizon (FAO, 2000; Soil Survey Staff, 2006). Normally, salt affected soils have poor physical properties. Excess sodium can induce crusted surfaces, flocculation or dispersion of clay minerals and organic matter, prismatic (later columnar) structure formation in the B horizon (White, 1964, Arshad and Pawluk, 1966; Ivanava and Bol'Shakov, 1972; SOS Environment, Inc., 2001). The amount of sodium attached to the soil particles increases to the point where sodium ions begin to predominate over the other main cations (calcium and magnesium), deleteriously affecting the physical properties in the soil, making the land susceptible to degradation. Sodium ions have a strong impact on the behaviour and properties of the soil. The relatively large size of hydrated sodium ions tends to decrease the attractive forces between the clay particles, thus encouraging dispersion of the particles (NSW SOE, 2000).

A soil is considered to be sodic when the adsorbed sodium reaches a concentration where it starts to affect soil structure. Sodicity adversely affects soil structure, soil water and aeration, porosity and soil strength and thus plant growth (Rengasamy and Sumner, 1998; Fitzpatrick *et al.,* 2001). Generally, salt affected soils have high bulk density (Heck and Mermut, 1992; Suddhiprakarn and Kheoruenromne, 1998). Clay is dispersed and worked into the subsoil, forming a dense accumulation horizon, the natric horizon. Clay in the topsoil is also decomposed in the high pH conditions resulting from the presence of Na_2CO_3 and of periodically low salt concentration combined with high exchangeable sodium, leading to the formation of the columnar or prismatic structures typical of the subsoil of sodic soils (FAO, 2000). Many soils can show a serious amount of clay dispersion with water percolation. This may be because their clay is of the Na-type (Takai *et al.,* 1987).

Salt affected soils have high electrical conductivity (EC), high exchangeable sodium percentage (ESP) and high sodium adsorption ratio (SAR) (Heck and Mormut, 1992; Suddhiprakarn and Kheoruenromne, 1998; Mali *et al.,* 2002). Most of saline and saline sodic soils have the pH value of less than 8.5 and the pH value of sodic soil is more than 8.5 (Brady and Weil, 2002).

Specific components of the soil solution in salt affected soil may also have a significant effect on mineral weathering. Soil weathering is enhanced with increasing exchangeable sodium percentage (Oster and Shainberg, 1979; Frenkel *et al.,* 1983; Kohut and Dudas, 1994). Alkaline conditions increased the solubility of Al and Si, thus promoting the interlayering in minerals with large expandable layers (Kohut and Dudas, 1994). Smectite degradation occurs with a concomitant increase in amorphous materials, within soil layers having the highest salt and soda content (Kishk and Hassan, 1972). Studies in North America have also indicated smectite alteration in soils affected by salts (Kohut and Dudas, 1994). Montmorillonite becomes disordered in the surface horizon of a Solonetzic soil (Klages and Southard, 1968). The decomposition of inherited smectite occurred in the sola of all sodium-affected soil and was most pronounced in the surface horizons (Mann and Boehm, 1983).

Genesis of Salt Affected Soils

Forming Factor of Salt Affected Soils

The formation and distribution of salt affected soils are increased due to natural and human-induced processes (Intvan, 1992; Ghassemi *et al.,* 1995). No single factor affected was responsible for their formation but many different interacting factors which will be discussed in the following sections. The lithology of the underlying rocks including their weathering processes both in the past and present time, the hydrological phenomena of the saline groundwater, climatic and topographic conditions and land utilization have been inherently the major causes of the salinization of soil (Harris, 1960; Várallyar, 1968; Timpson *et al.,* 1986; Skaris *et al.,* 1987; Takai *et al.,* 1987; Seelig *et al.,* 1990; Yuvaniyama *et al.,* 1996; Wentz and Vanderpluym, 1998; Haluschak, 2000; Caballero *et al.,* 2001).

Parent Material

Parent material is most important factor for salt affected soil formation, especially the occurrence of primary salinization. Most salt affected areas are underlain by salt formation and marine deposits in deeper geological layers (Várallyay, 1968; Takai *et al.*, 1987; Chhabra, 1996). Salt affected soils primarily are formed as a result of the long-term influence of natural processes leading to an accumulation of salts in a region. Accumulation of salts may be the result of a gradual accumulation of products of weathering or one-time submergence of soils under seawater (Ghassemi *et al*., 1995). Salt accumulates in the soil as a result of natural weathering process. However under humid condition salts percolate (leach) through the soil and are transported to the sea by streams and rivers. Under arid and semiarid conditions these weathering products accumulate *in situ* and result in development of salinity or alkalinity (Chhabra, 1996).

Topography

Salinity generally occurs in discharge areas where the water table is high. Salt affected soils are associated with the edges of closed depressions or low lying areas where the discharge of groundwater can occur and where water loss due to evaporation is high (Haluschak, 2000; Caballero *et al.,* 2001). Generally it is hypothesized that salinization is caused by capillary rise from a saline water table or concentration of salt in irrigation water in the field due to lack of adequate drainage facilities (Ceuppens *et al.,* 1997). Saline seeps from where leaching water carrying dissolved salts reaches a conductive layer and moves laterally to either a surface or subsurface discharge area. Saline seepage occurs when water in excess of crop use leaches soluble salts from the root zone and transports them laterally to lower landscape positions (Timpson *et al.,* 1986). Seepage of runoff water collected in ditches raises the water table adjacent to the drains and evaporation causes salts to accumulate near the soil surface (Skarie *et al.,* 1986). Saline seep formation is a function of climatic condition, groundwater flow system, surface drainage patterns and agricultural practices (Wentz and Vanderpluym, 1998). Irrigated agriculture in arid and semiarid environment carries a risk of soil degradation attributed salinization from poor irrigation management (Ceuppens *et al.,* 1997).

In some cases, salt accumulates in seepage spots at low points or side slopes in the landscape. In this case the groundwater flow is mainly lateral and down slope and occurs most often over a shallow and less permeable layer (Abrol *et al.,* 1988). Mineral containing water from fossil deposits of salt or from soil weathering in upland areas moves down the slope toward the lower basin, either on the surface during torrential storms or as groundwater on top of impervious geological layers. When the water in low-lying areas evaporates, it carries the salt up to or near the surface, where the salts accumulate (Brady and Weil, 2002). In some other cases textural changes in the material constituting the aquifer and change in the slope of the topographic surface could cause the saline seepage. Topography of the basement rocks can play a major role in the development of dryland salinity. The movement of saline groundwater can be restricted by shallow basement rock (Ghassemi *et al.,* 1995). Seelig *et al.* (1990) studied characteristics and taxonomy of sodic soil as a function of landform position. They reported that transitional position between the upland and wetland positions, the intermediate position, was dominated by somewhat poorly drained Leptic and Udic Natriborolls. Rojanapremsuk (1990) studied characteristics of salt affected soil in Nam Pong Irrigation Project Stage 2, Thailand, and reported that most of salt affected soils within this area occupy washed footslopes and local depression in the basin.

Climate

Salt affected soils are found in mixed environment, especially in arid and semiarid regions because there is insufficient rainfall for leaching salt from the soil layers (Brady and Weil, 2002). Important climatic factors affecting these soils are wind speed, solar radiation, temperature, humidity, precipitation, evaporation and soil temperature (Wentz and Vanderpluym, 1998; Bettany, 2002). Wentz and Vanderpluym (1998) reported that salinity levels were moderate to strong in spring and low to moderate in the fall, the expected seasonal pattern. Usually the water table is shallowest in the spring because of the large amount of water from spring snowmelt. As a result, salt concentrations in the root zone are generally highest in the spring.

Vegetation

Plants can be used as indicators of saline and sodic conditions, because tolerance varies with plant species (Seelig, 2000). The composition of plant communities in areas of salt affected soil has been related to the soil water regime and level of salinity in the soil (Redmann, 1972). Plant communities in saline areas exhibit two common characteristics, low species diversification compared with adjacent non salt affected soil areas and plant communities in saline areas often exist as concentric zones (Dodd and Coupland, 1966; Ungar, 1967, 1970, 1974). Deforestation has substantially increased the source of water for recharge and resulted in a rise of saline groundwater in the discharge area, that used to be below the range of capillary movement and the upward movement of the groundwater near the soil surface (Williamson *et al.*, 1989). Deforestation has increased saline seepage on lower slopes and bottomland (Takai *et al.*, 1987).

Time

Time related aspects in soil genesis and classification include stages of soil development over time, absolute dating of soil profiles and their horizons, time rates of soil formation and relation of soil age to slope and landscape position occupied by the soil (Buol *et al.*, 2003). Salt affected soils can occur in all developed soils. Generally, they occur in medium to high soil development such as Inceptisols, Mollisols and Alfisols. However, dryland salt affected soils and coastal salt affected soils occur in Aridisols and Entisols (Al-Janabi and Lewis, 1982; Seelig *et al.,* 1990; Suddhiprakarn and Kheoruenromne, 1998; Soil Survey Staff, 2006).

Pedogenic Processes of Salt Affected Soils

Genesis and distribution of salt affected soil depend on five processes, namely salinization, desalinization, alkalization, dealkalization and solodization (Sys, 1980; Pawluk, 1982). In addition, resilication processes can occur in salt affected soils due to increased pH as a result of the salinity which then effects the solubility of silicon (Buol *et al.,* 2003).

Salinization

This is the most important process for formation of salt affected soil. This process is the cause of salt accumulation in saline soil. The salinization is associated with the hydrologic conditions of the surface deposits and especially the level of the groundwater. Salinization operates chiefly in subhumid, semiarid, and arid regions and also in some coastal humid area, wherever depressions are enriched in salts faster than they are leached. Salt accumulation is preferential in depressional soils with a high content of clay and low permeability, with reduced leaching. Sulfates and chlorides are the predominant salts in saline soils (Chadwick and Graham, 2000; Buol *et al.,* 2003).

Desalinization

This process is important for the development of saline-sodic soil and sodic soil. Desalinization is most frequently used with reference to the removal by leaching of soluble salts from horizons or the total soil profiles that have previously contained enough soluble salt so that plant growth was impaired. Therefore, it is a process that can be active only after soluble salts have accumulated, that is, salinization (Chadwick and Graham, 2000; Buol *et al.*, 2003).

Alkalization

Alkalization is another major processes in the formation of salt affected soils. This involves the accumulation of sodium ions on the exchange sites of the clay. All cations in solution engage in a reversible reaction with the exchange sites on the clay and organic matter particles. (Chadwick and Graham, 2000; Buol *et al.*, 2003).

Dealkalization

Dealkalization refers to the removal of the Na^+ ions from the exchange site. This process also increases the dispersion of clay. Dispersion occurs when the Na^+ ion becomes hydrated. Much of the dispersion can be eliminated if Ca^{++} and/or Mg^{++} ions are concentrated in the water used to leach the alkali soil as they can replace the Na^+ in the exchange complex. (Chadwick and Graham, 2000; Buol *et al.*, 2003).

Solodization

Solodization refers to the removal of sodium ions from the exchange complex due to continued leaching of the soil profile. In this process, further leaching even removes the sodium ions, leaving behind hydroxyl ions in the soil solution. A change in climate such that increased rainfall further leaches the sodium ions out of the exchange complex. This can also be caused by irrigation and snowmelt accumulations in low-lying area over time (Henri, 1999).

Resilication

Resilication refers to the addition of silica to a clay mineral structure in soil, saprolite or sediment, thereby converting it to another species. It is caused by the presence of excess $Si(OH)_4$ in the system. Resilication is the formation of kaolinite from gibbsite or formation of montmorillonite from kaolinite in presence of large amounts of $Si(OH)_4$ at high pH (Buol *et al.,* 2003).

Properties of Salt Affected Soils

Morphology

Soil morphology is observed, described, and studied under field conditions (Buol *et al.,* 2003). The major morphological properties found in salt affected soils include the accumulation of soluble salts in the soil profile. The Na^+ accumulation results in the occurrence of a natric or salic horizon (FAO, 2000; Soil Survey Staff, 2006). Morphological properties that are present in the soil surface are white efflorescence, salt crusts, non-aggregated brown powder, black salt deposits and evaporative salt crystals (FAO, 2000).

The surface of salt affected soils may be bare because the high soluble salt and the sodium content inhibits the growth of most plants (Harris, 1960). Normally, saline and saline-sodic soils have a salt crust in surface soil and sodic soils experience the flocculation or dispersion of clay minerals and organic matter (Harris, 1960; Arunin, 1992; FAO, 2000; Karimpour, 2002). Sodic soils have a dense layer of clay at or near surface. This natural layer, often called a claypan is barrier to roots of plant. Surface crusting is a common problem with cultivated sodic soil. When dry, the surface forms a hard crust that is a barrier to seedling emergence (Seelig, 2000). Seelig *et al.* (1990) reported that normally, sodic soil has a black color.

Physical Properties

Normally, salt affected soils have poor physical properties. Sodium can induce crusted surfaces which prevent water percolation, causing runoff and erosion (SOS Environment, Inc., 2001). Salt affected soils normally have different colors depend on soil forming factor and pedogenic processes of the soil development.

Suddhiprakarn and Kheoruenromne (1998) reported that salt affected soils in Central Plains of Thailand have different colors. In lowland areas they have low chroma and with the presence of mottles. In upland they have brown to dark brown colors. Many researchers have studied salt affected soils in Northeast Thailand. They reported that these soils normally have a hue of 10YR and mottles are present in some areas (Rojanapremsuk, 1990; Vichiansinpa, 1992; Songsawadi, 1994; Promdecha, 2001). Seelig *et al.* (1990) studies characteristics and taxonomy of sodic soil as a function of landfrom position. They reported that sodic soil have black colors in the surface horizon and have brown colors in subsoil horizons.

Salt affected soils have various textures, ranging from sand to clay (Seelig *et al.,* 1990; Heck and Mermut, 1992; Radogna and Padovano, 1992; Topark-Ngarm *et al.,* 1992). Thus the texture of salt affected soils is related to the nature of soil formation and their parent material.

The structure of salt affected soils results from the accumulation of sodium ions in the soil. The sodium ion has a major impact on the flocculation or dispersion of clay minerals and organic matter. In addition, sodium ions also influences infiltration in these soils. The damage to soil structure can be due to salinity and sodium accumulating conditions (Karimpour, 2002). Na_2CO_3 may be formed in these soils by evaporation of water containing sodium bicarbonate or by biological reduction of sodium sulfates. Clay is dispersed and moved into the subsoil, forming a dense accumulation horizon, the natric horizon (FAO, 2000). Generally, profiles of salt affected soil have thick eluvial horizon of translocated clay accumulated in an argillic horizon, but the stage at which the characteristic prismatic (later columnar) structure of the B horizon forms varies. Some researchers found soils in which clay translocation and eluvial horizon formation apparently occurred before prismatic structure formed in the B horizon (Arshad and Pawluk, 1966; Ivanava and Bol'Shakov, 1972). White (1964) described soils in which the prismatic struture may have formed before a significant amount of eluviation.

The bulk density of salt affected soil is generally high (Hoontrakul, 1988; Rojanapremsuk, 1990; Vichiansinpa, 1992; Songsawadi, 1994; Promdecha, 2001). With increasing depth, the bulk density value increases (Heck and Mermut, 1992; Suddhiprakarn and Kheoruenromne, 1998).

The assessment of the effects of salinity and sodicity on hydraulic conductivity of soils was of interest for many researchers. They found that a reduction of hydraulic conductivity depended on the sodium adsorption ratio and concentration of soluble salt (Shainberg and Singer, 1985; Samani, 1992; Karimpour, 2002). Abu-Sharar *et al.* (1987) studied saline and sodic soils. They reported that, the reduction of hydraulic conductivity was correlated with aggregate dispersion.

Soils high in sodium may present physical restrictions to plant growth. When sodium is attached to clay particles the forces that hold clay particles together are greatly weakened when sodium-clay and water come into contact. In this condition clay particles are easily detached from aggregates, i.e. dispersed (Seelig, 2000).

Chemical Properties

Salt affected soils are characterized and classified on the basis of chemical properties. Four measurements are involved for the most part: 1) an approximation of the content of soluble salt in the soil (EC), 2) a measurement of the exchangeable sodium percentage (ESP), 3) the sodium adsorption ratio (SAR) and 4) the pH value (Ghassemi *et al.,* 1995; Mickey and Kristiansen, 2001). These properties are most important for classifying salt affected soils into three groups as previously indicated.

Saline and saline-sodic soils have high EC (more than 4 dSm^{-1}) and the sodic soils have an EC less than 4 dSm^{-1} (Heck and Mermut, 1992; Suddhiprakarn and Kheoruenromne, 1998; Brady and Weil, 2002; Mali *et al.,* 2002). Generally, the EC of the soils is highest in the surface horizon, especially when the soils have salt crust on the surface. Changes of EC values are generally related to season, climate, sources of salt and depth of water table.

The SAR of saline soil is less than 13 and of saline-sodic and sodic soils is more than 13. The SAR gives information on the comparative concentrations of Na^{+}, Ca^{++} and Mg^{++} in soil solution. It is calculated as follows (Brady and Weil, 2002):

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

The ESP of saline soil is less than 15 and in saline-sodic and sodic soils it is more than 15. The ESP identifies the degree to which the exchange complex is saturated with sodium. It is calculated as follows (Brady and Weil, 2002):

$$ESP = \frac{Exchangeable\ sodium,\ cmol/kg}{Cation\ exchange\ capacity,\ cmol/kg} \times 100$$

Salt affected soils have high soluble salt in soil solution (Heck and Mermut, 1992; Suddhiprakarn and Kheoruenromne, 1998). The exchange complex of saline soil is often dominated by calcium and magnesium. As a consequence, the ESP is less than 15. The exchange complex of saline sodic and sodic soils is dominated by sodium. The Na^{+} ion concentration in the soil solution of saline soils may be somewhat higher than that of Ca^{++} or Mg^{++} due to the presence of soluble salts that are commonly high in sodium. However, because of the greater affinity of the soil colloids for divalent cations, such as Ca^{++} or Mg^{++}, the SAR of saline soil is less than 13 (Brady and Weil, 2002).

Most saline and saline sodic soils have a pH value in saturated extract less than 8.5 and the pH value of sodic soil is more than 8.5. The high pH is largely due to the hydrolysis of sodium carbonate.

$$2Na^{+} + CO_3^{2+} + H_2O \rightleftharpoons 2Na^{+} + HCO_3^{-} + OH^{-}$$

The sodium on the exchange complex also undergoes hydrolysis (Brady and Weil, 2002).

$$Na^{+}\ \boxed{\text{Micelle}} + H_2O \rightleftharpoons H^{+}\ \boxed{\text{Micelle}} + Na^{+} + OH^{-}$$

High pH (7.8 to 8.5) generally occurs in sodic soils. 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 form hydroxyl (OH^-) ions that cause high pH (Seelig, 2000).

Mineralogical Properties

The clay mineralogy of salt affected soils from various areas is remarkably similar, and it is dominated by smectite, with smaller amounts of mica, kaolinite and chlorite (Kodama, 1979; Abder-Ruhman, 1980; Dudas and Plwluk, 1982). Many workers have studied salt affected soils in Thailand. They found that clay minerals of salt affected soils include smectite, kaolinite and illite. Generally, kaolinite is the dominant clay minerals with the trace of smectite (Hoontrakul, 1988; Vichiansinpa, 1992; Songsawadi, 1994; Suddhiprakarn and Kheoruenromne, 1998; Promdecha, 2001). The amount of smectite increases in salt affected soils and may be higher than kaolinite in some parts of the area. This may be the result of the salinity effect increasing the solubility of silica that induces the resilication process. It can be concluded that the amounts of smectite have close relationship with resilication (Buol *et al.*, 2003). This 2:1 phyllosilicate is a highly expansive mineral. Most of the ionic substitution occurs in the octahedral layer. It can adsorb cations in interlayer also it can accumulate more cations than 1:1 phyllosilicates (Rojanapremsuk, 1990).

The stability of clay minerals in extremely saline alkaline soils is not well understood, but may be expected to differ from those in other soils due to differences in the geochemical environment. The dissolution of common silicate minerals such as kaolinite, muscovite, quartz and feldspars increases with increasing pH in alkaline soil solution. Mineral characteristics will also be affected by the composition of the soil solution. The rate of quartz dissolution increases due to the high electrolyte content in salty soil solution (Kohut and Dudas, 1994).

The composition of salts reflects their origin, as well as the changes in the hydrochemical regimes regulated by the zonal and local geomorphological and hydrogeological conditions. The principal salts involved in salt affected soils are the following: $NaCl$, $CaCl_2$, $MgCl_2$, $NaHCO_3$, Na_2CO_3, $NaSO_4$, $MgSO_4$, $CaSO_4$ and $NaNO_3$ (Zonn, 1986). In arid and simi-arid areas generally the salts are sulfate, carbonate and bicarbonate (Keller *et al.,* 1986; Fitzparick *et al.,* 1996; Williams and Semple, 2001). Most salt affected soils in Thailand and Australia have high amounts of sodium chloride (Isbell *et al.,* 1983; Hoontrakul, 1988; Vichiansinpa, 1992; Songsawadi, 1994; Suddhiprakarn and Kheoruenromne, 1998; Promdecha, 2001). With a change from arid to humid-tropical hydrotermal regimes, the amounts of soluble salt in the soil, such as $NaCl$, $CaCl_2$ and $MgCl_2$, decrease while those of less soluble sulfates relatively increase. Under tropical conditions, one encounters relatively larger quantities of $NaHCO_3$ and Na_2CO_3 because of their peculiar soda formation (Zonn, 1986).

Micromorphological Properties

Micromorphological characteristics of soils are important for the determination of soil processes that can affect agricultural use. The micromorphological properties of salt affected soils are different from other soils because of environmental factor and pedogenic processes (Buol *et al.,* 2003). Salinity and salt in soil causes micromorphological features of soil to change. However, the study of micromorphological properties of salt affected soil has been limited. The result of previous studies indicate that some micromorphological feature found in salt affected soils are due to salinity including effects such as accumulation of salt in soil profile, but some micromorphological characteristics of saline soils are derived from other environmental factors affecting their genesis.

Several researchers have studied the micromorphological properties of salt affected soils, they found the accumulation of salt or salt crystal in the soil profile and in vughs (Kooistra, 1983; Rojanapremsuk, 1990; Vichiansinpa, 1992). The diagnostic subsurface horizons of salt affected soil show the accumulation of clay and salt, classified as natric horizon (Rojanapremsuk, 1990; Vichiansinpa, 1992). Skeleton grain runi-quartz was found with other substances inside the grains. Pores in these soils generally are vughs and channels (Vichiansinpa, 1992; Suddhiprakarn and Kheoruenromne, 1998).

Kooistra (1983) conducted a study using the light microscope and submicroscope observation of salts in marine alluvium (India) and found that salt affected soil showed a special kind of salt efflorescence on void-walls. This salt efflorescence on void-walls is halite, and can be observed with the scanning electron microscope (SEM).

Suddhiprakarn and Kheoruenromne (1998) reported that micromorphological characteristics of salt affected soils in Central Plains of Thailand indicate influence of marine deposits and calcareous materials derived from nearby limestone areas. Pores in soil where salt can accumulate are mainly vughs. In the lowland situation cracks and fissures are also present. Clay accumulation features such as pedotubules related to large pore (vughs) and some concretions or nodules of iron oxides and iron-manganese oxides also occur in these salt affected soils.

Vichiansinpa (1992) studied salt affected soils in Khorat Basin, Thailand and reported that salt affected soils show the accumulation of salt or salt crystal of chloride and carbonate in soil pores which are mainly vughs and channels. The subsoil also has a clay accumulation and ferri-argillan in soil pores and on the surface of coarse grains. The soils have a natric horizon and the salt effect can clearly be observed. In addition, he also found accumulations of nodules and concretions of Fe-oxide and Mn-oxide, carbonate nodules and runi-quartz in the soils. The accumulation of Fe-oxide and Mn-oxide indicates that, soil system has experienced oxidation-reduction processes.

Salt accumulation in soil indicates that the soil environment has a poor leaching condition (Fanning and Fanning, 1989; Buol *et al.*, 2003).

Salt Affected Soils in Thailand

Distribution

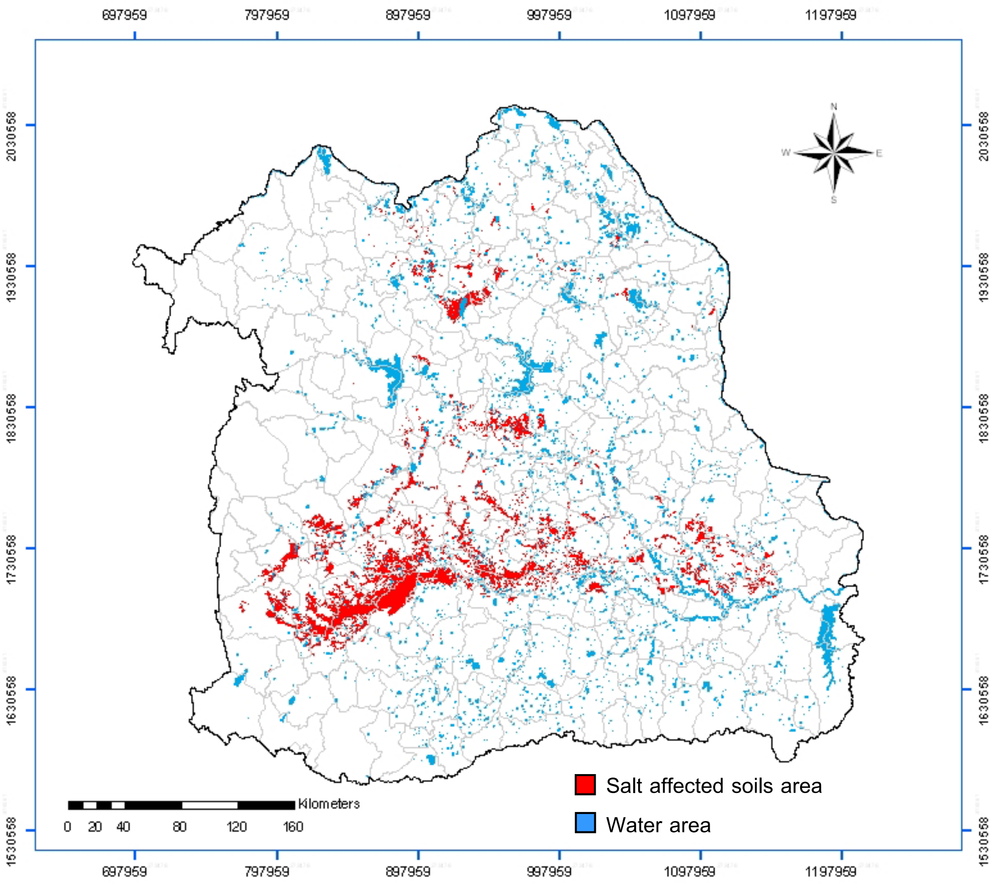
In Thailand, there are two major types of salt affected lands. These salt affected lands occupy some coastal areas (coastal saline soils) including part of the Central Plain and inland area of the Northeast Plateau basin (inland saline soils). Their total extent is 3.61 million hectares. Seventeen percent of the salt affected soil area or 2.85 million hectares is in the Northeast whereas other areas of 0.58 million hectares and 0.18 million hectares are along the coast and in the Central Plain respectively (Arunin, 1992).

Coastal Saline Soils

The coastal saline soils are scattered along the coast of Peninsular Thailand and Southeast Coast regions and some areas of Central Plain. The coastal saline soils are very young soils, high in clay and silt with little profile development (Glopper, 1971; Arunin, 1992). The coastal salt affected soils may be characterized as heavy clays, and some acid sulfate soils and they are subject to tidal influences and saline groundwater intrusion. The Soil Survey Division (1999) reported the distribution of salt affected soils in the Central Plain covers of six provinces including Nakhon Pathom, Suphan Buri, Kanchanaburi, Sing Buri, Ang Thong and Chai Nat. These provinces are on old deltas and young deltas, which had been affected by marine influences in the past. The Central Plain salt affected soils have generally developed from the old marine sediments (Hattori and Takaya, 1989).

Inland Saline Soils

Inland saline soils are in the Sakon Nakhon and Khorat basins of the Northeast Plateau (Arunin, 1992). These two basins cover 15 provinces. The map of salt affected soils distribution in Northeast Thailand is showed in Figure 1. According to the soil maps of each province in the Northeast Thailand the salt affected soil series are Udon, Kula Ronghai, Khorat saline variant, Roi Et saline variant and some areas of Phimai series (Panichapong, 1981). The Department of Land Development (1991) compiled various soil maps of salt affected soils. The map units are classified by the presence of salt patches on the soil surface into severe saline soil (0.24 million hectares), moderate saline soil (0.59 million hectares), slight saline soil (2.02 million hectares), potential salt source area (3.14 million hectares) and salt free area (10.9 million hectares) (Yuvaniyama, 1994).



Source: Department of Land Development (2003)

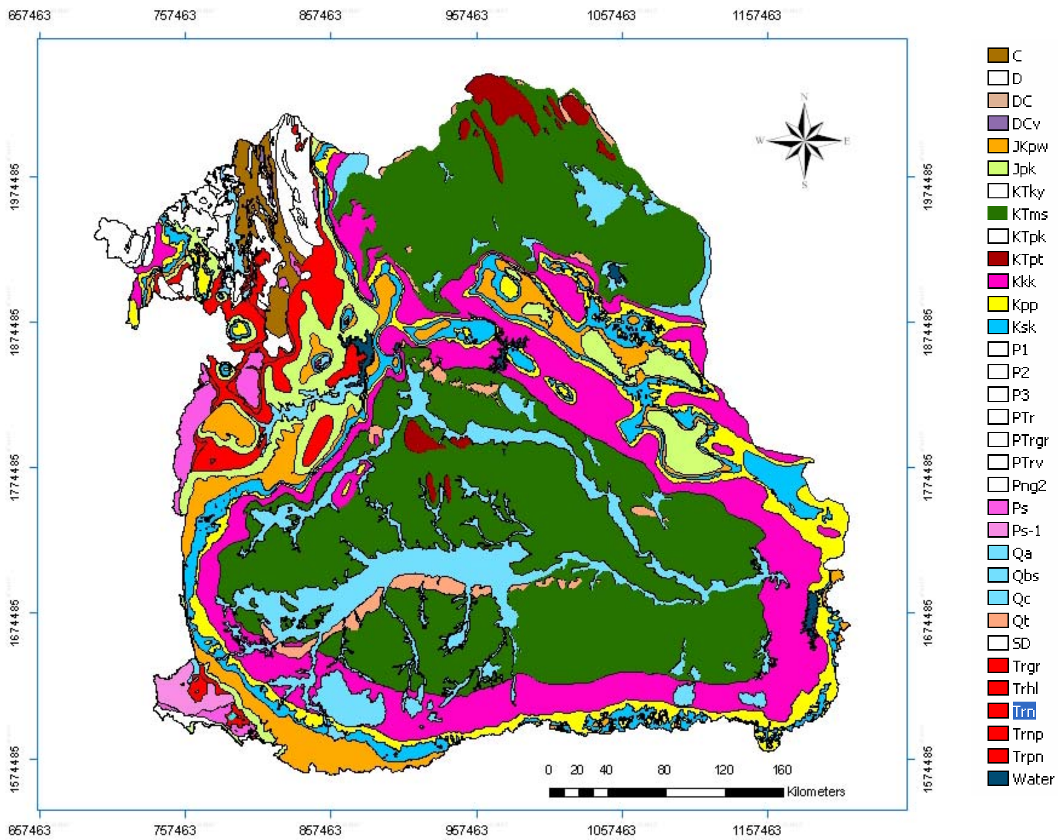
Figure 1 The areas of salt affected soils in Northeast Thailand.

Genesis

The formation of salt affected soils in Thailand is affected by natural and human-induced processes. No single factor can explain salt affected soil formation in Thailand. The most important factor is parent material. Most salt affected soils are underlain by salt formation and marine deposits in deeper geological layers (Takai *et al.,* 1987; Chhabra, 1996). The formation of salt affected soils is closely related to geology and landform. Figure 2 illustrates the geologic map of Northeast Thailand (Department of Mineral Resources, 1985) and the key to the abbreviated rock formation is showed in Table 1. The Northeast areas are underlain by salt bearing rocks (Sinanuwong *et al.,* 1974; Takai *et al.,* 1987). Salts are mainly derived from the rock of the Maha Sarakham Formation of the Mesozoic Khorat Group (KTms). Both Khorat and Sakon Nakon basins are underlain by an evaporite salt-bearing formation with beds and lens of halite (rock salt) up to 250 m thick (Piancharoen, 1973). The salt formation consists predominantly of sandstone, shale and siltstone (Takai *et al.,* 1987).

The formation of salt affected soils in the Coastal and Central Plain is affected by the accumulation of salt that mostly originated from the ocean via rainfall and marine deposition in earlier geological periods (Isbell *et al.,* 1983). Coastal saline areas vary widely in terms of soil salinity, and the salinity and depth of groundwater, as well as salinity of surface water (MOP, 1986; Mondal *et al.,* 2001). The main reasons for soil salinity in these areas include seawater intrusion, irrigation with low quality water due to high concentration of salt in groundwater as it is located at the downstream regions of the system and an inadequate field drainage (Kotb *et al.,* 2000).

There are three published hypotheses about the formation of salt affected soils in Northeast, Thailand.



Source: Department of Mineral Resources (1985)

Figure 2 The geological map of 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 are 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).

Table 1 The key to the abbreviated rock formations in the geologic map of Northeast Thailand.

Symbol	Age	Formation name
C	Carboniferous	No data
D	Devonian	No data
DC	Devonian-Carboniferous	No data
DCv	Devonian-Carboniferous	No data
JKpw	Jurassic-Cretaceous	Phra Wihan Formation
Jpk	Jurassic	Phu Kradung Formation
KTky	U Cretaceous-Tertiary	Khao Ya Puk Formation
KTms	U Cretaceous-Tertiary	Mahasarakham
KTpk	U Cretaceous-Tertiary	Phu Khat Formation
KTpt	U Cretaceous-Tertiary	Phu Tok formation
Kkk	L Cretaceous	Khok Kroat Formation
Kpp	L Cretaceous	Phu Phan formation
Ksk	L Cretaceous	Sao Khua Formation
P1	Permian	Nam Mahoran
P2	Permian	
P3	Permian	Phadua
PTr	Permian-Triassic	No data
PTrgr	Permian-Triassic	No data
PTrv	Permian-Triassic	No data
Png2	M Permian	Pha Huat Formation
Ps	Permian	
Ps-1	L Permian	No data
Qa	Quaternary	No data
Qbs	Quaternary	No data
Qc	Quaternary	
Qt	Quaternary	
SD	Silurian-Devonian	No data
Trgr	Triassic	No data
Trhl	U Triassic	Huai Hin Lat Formation
Trn	L Triassic	Noen Phuyai Yua Formation
Trnp	U Triassic	Nam Phong Formation
Trpn	M-U Triassic	Pong Nam Ron Formation
Water		

Source: Department of Mineral Resources (1985)

A secondary salinization of the soil has also been observed. It has been reported that until recently in many areas, rice cultivation on the lower slope or bottomland was possible and well water on the upland was drinkable. At present, those areas are severely affected by salt and well water has become brackish and unsuitable for drinking. Deforestation, extensive land clearing, saline seepage, rising saline groundwater or saline irrigation water may cause secondary salinization of the soils in this area (Takai *et al.,* 1987).

Classification

Salt affected soils in Thailand can be classified into four groups: saline, saline sodic, sodic, and acid sulfate saline soils (Takai *et al.*, 1987; Hattori and Takaya, 1989; Arunin, 1992).

Results of several studies reveal that most of salt affected soils in Thailand are Alfisols and Inceptisols. They are Natraqualfs, Endoaquepts, Natrustalfs and Haplustalfs (Hoontrakul, 1988; Rojanapremsuk, 1990; Vichiansinpa, 1992; Songsawadi, 1994; Suddhiprakarn and Kheoruenromne, 1998; Promdecha, 2001).