Agronomic Management of Saline Soil in Agricultural Lands of Thailand

（タイ国の農地における塩類土壌の農法的管理）

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2016

Abstract

Salt-affected (saline) soils in Thailand cover an area of 2.302 million hectares and management of the inland saline soils is often problematic. Appropriate agronomic management is typically prescribed for slightly to moderately salt-affected lands used for rice cultivation. Application of green manure, specifically the leguminous *Sesbania rostrata*, has been identified as having active potential in salt-affected soils for rainfed lowland rice systems. However, for severely salt-affected soils, rehabilitation is often necessitated, requiring high investment and changes in cropping pattern. Halophytes have a role in revegetation of such areas and contribute to environmental remediation. In addition, reforestation of the recharge uplands (the potential salt source area) can also lower the water table in some situations and reduce the discharge to lowland areas, offering an additional approach for salinity control.

From the perspectives of cost-performance, natural environment and the country's farmers' capacity, site specific Agronomic Management best serves the interests of Thailand. For inland saline soil in the northeast region, it was found that the utilization of green manure, especially *Sesbania rostrata*, is suitable. The findings showed a yield response of rice to *S. rostrata* in saline soil in the northeast region. Application of green manures increased rice yields by up to 30 % while decreasing soil electrical conductivity. However, utilization of *S. rostrata* as green manure has remained constrained by many factors such as insufficient availability of seed, low seed germination, photoperiod sensitivity, difficulty with rice transplanting after incorporation and increased variable costs (especially labor). For coastal saline soil, utilization of salt tolerant species such as Dixie grass (*Sporobolus virginicus* coarse type), Smyrna grass (*Sporobolus virginicus* smooth type), Seabrook grass (*Distichlis spicata*), and Georgia grass (*Spartina patens*) could help improve soil properties. It was found that Seabrook grass showed the best performance. In general, soil organic matter as well as phosphorus and potassium levels were increased, while soil electrical conductivity decreased. The use of organic fertilizer (such as compost, farmyard manure and bio-extract) plus chemical fertilizer tended to give yields higher than for either chemical fertilizer alone, or the control, in central plain saline soil. After the experiment, the soil electrical conductivity (EC_e) changed slightly. However, the change in EC_e found was variable. Soil organic matter tended to decrease while the available phosphorus tended to increase. Generally, available potassium tended to increase except in the control treatment and the treatment with chemical fertilizer alone.

However, agricultural problem soils cannot be solved by one agency alone. Thus, stakeholder participation is required for sustainable land management. A Community Participatory Network was considered and established in the pilot provinces of Nakorn Ratchasima and Khon Kaen. This network is used for the management of salinity problems and the prevention of soil salinity in all relevant locations. The action plan for saline soil management was established at both the community and household levels.

Keywords: saline soil, agronomic management, green manure, salt tolerant species, organic fertilizer

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Acknowledgements

This research was completed with much support from researchers at the Land Development Department of Thailand and assistance from lecturers of the College of Bioresources Science, Nihon University. I wish to express my sincerest gratitude to institutes and people who made substantial contributions to the completion of this dissertation as follows:

Prof. Dr. Eiichi Kohno, Dean of the College of Bioresources Science, Nihon University, and supervisor of this dissertation, offered enlightened guidance, valuable comments, suggestions, assistance and encouragement towards the completion of this dissertation. I would also like to thank Prof. Dr. Kingshuk Roy who played an important role providing useful comments, suggestions and guidance. And I would like to thank Dr. Katsuhiro Sasada for assisting with my stay in Japan.

I wish to express my sincerest gratitude to Dr. Rungsun Im-Erb, a former staff member of the Land Development Department who gave valuable comments and suggestions on this dissertation.

I would like to thank the Land Development Department, and the College of Bioresources Science, Nihon University and their staff for their assistance with field research and preparation of this document.

A very special note of appreciation is expressed to my father, mother, wife and daughters for their concern, self – sacrifice and encouragement both directly and indirectly.

Chapter 1

Introduction

1.1 Purpose and structure of dissertation

1.1.1 Purpose of dissertation

a) To find out site-specific methods of using appropriate agronomic management with different salt tolerant species in the saline soils of Thailand.

b) To determine soil productivity while using the appropriate agronomic management with different salt tolerant species in the saline soils of Thailand.

The originality of this research is to determine the best agronomic management (site-specific) in all types of saline soils (lowlands) in Thailand.

1.1.2 Structure of dissertation

This dissertation is divided into two parts as following.

a) The present status and management of salinity in Thailand.

The first part will explain the present status and management of salinity in Thailand. This includes the definition and appearance of saline soil, present status of salinity and present management of saline soils. Agronomic management, biological/chemical management and engineering management are described.

b) The reporting of experimental findings on agronomic management in all types of saline soils.

This part will summarize the empirical study of agronomic management of saline soils in agricultural land. The agronomic management depends on the type of saline soils and the salinity level. Utilization of green manure, namely *Sesbania rostrata*, is suitable for rice cultivation on inland saline soil, while utilization of salt tolerant species was studied for rehabilitation of coastal saline soil. For central plain saline soils, the study emphasized the utilization of organic fertilizer with appropriate cultivation to increase crop yield. Furthermore, a community participatory network was established in pilot areas for sustainable management. Agricultural problem soils cannot be solved by one agency alone so community participation on sustainable land management is required.

1.2 Review of literatures

1.2.1 Definition and appearance of saline soil

Saline soil is one of the agricultural problem soils. It is one of the most widespread soil degradation processes on the Earth. Abrol *et al*. (1988) summarized that these problems are most widespread in the arid and semi-arid regions, but salt affected soils also occur extensively in sub-humid and humid climates. The problems of salt-affected soils are long standing and reduce the soil productivity, eventually leading to loss of cultivable land. Salinity is also a serious problem in areas where groundwater of high salt content is used for irrigation.

Salt-affected soils are soils containing high levels of soluble salts. They show high electrical conductivity of the saturation extract from soil samples (EC_e), exceeding 2 dS m^{-1} at 25^oC (Abrol *et al*., 1988). The United States Salinity Laboratory Staff, USSLS, (1954) divided salt-affected soils into 3 types.

- Saline Soil is the soil with EC_e of more than 4 dS m^{-1} and the exchangeable sodium percentage (ESP) is less than 15. Ordinary soil pH is less than 8.5.

- Nonsaline-Alkali Soil is the soil with EC_e of less than 4 dS m^{-1} and the ESP is more than 15. Soil pH usually ranges between 8.5 and 10.

- Saline-Alkali Soil is the soil with EC_e of more than 4 dS m^{-1} and the ESP is higher than 15. Ordinary soil pH is higher than 8.5.

Every year the acreage of saline soils is increasing and causing major problems for farmers in managing the land (Wongsomsak, 1986). Salinity problem has resulted in reducing agricultural potential (Ladeiro, 2012). The most common soluble salts are chlorides and sulfates of sodium, calcium and magnesium. Nitrates may be present in appreciable quantities only rarely. Sodium and chloride are the most dominant ions, particularly in highly saline soils.

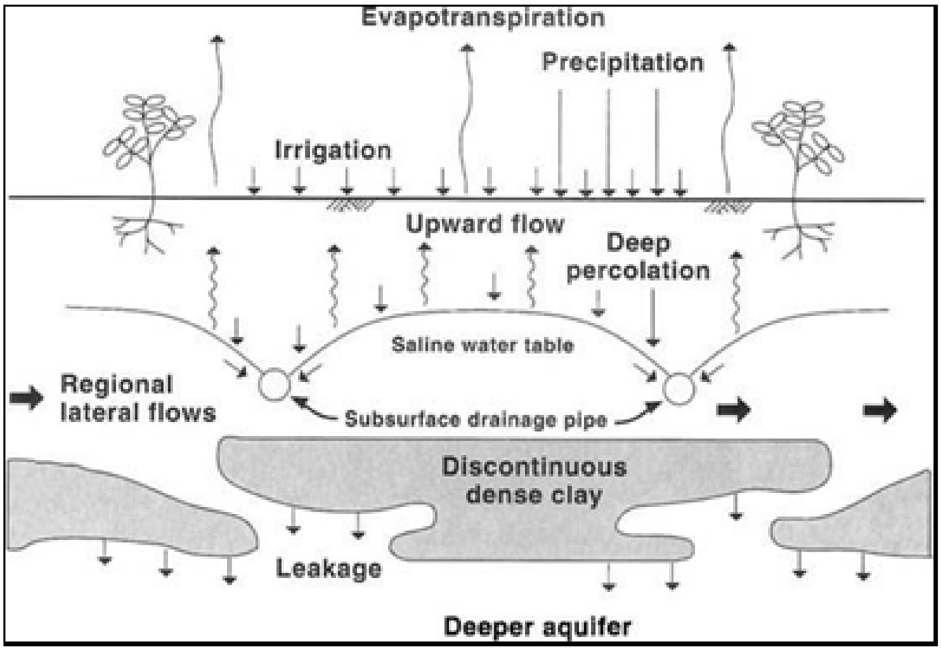
1.2.2 Mechanism/Process of soil salinity

The processes of salinization in agricultural lands involve mechanisms of salt mobilisation and accumulation as shown in **figure 1.1** (www.californiaagriculture.ucanr.org).

- Salts are dissolved and mobilised by surface water and groundwater (All sites).

- Rising groundwater (saline) remobilises salts previously stored at depth in the soil (Inland sites).

- Salts are concentrated at, or near, the earth's surface by evaporation (All sites).



Source: californiaagriculture.ucanr.org

Figure 1.1 Mechanisms of salt mobilization and accumulation

1.2.3 Measuring salinity status

A simplified procedure for measuring salinity consists of mixing a soil sample with sufficient water to produce a saturated paste and then extracting the solution for measurement of conductivity. Measuring the electrical conductivity (EC) of a saturation extract has an advantage in that saturation percentage is directly related to field moisture range (USSLS, 1954). The standard unit of conductance is Siemens and when expressed per unit of distance, the standard unit of conductivity is Siemens per metre. For convenience, therefore, conductivities of soil extracts are expressed in deci Siemens (dS) per metre at 25°C. EC measurements are quick and sufficiently accurate for most purposes. The solution is placed between two electrodes of constant geometry and constant distance of separation. However, the four electrode technique for measuring bulk soil electrical conductivity has been developed (Rhoades, 1976) for use on irrigated soils and on dry land saline seeps in the field.

1.2.4 Sources of salt

Soil salinization has numerous origins, namely, natural causes stimulated by, for example, the microscopic salt particles carried by the wind inland from the oceans, or, some anthropic causes (secondary salinization) (Yensen, 2006), among which irrigation water quality is one of the most important. These are similar to saline soils in Thailand, resulting from both natural and anthropogenic salinization processes (Sinanuwong and Takaya, 1974; Wongsomsak, 1986). The source of salt in this area is halite. Besides the inherent salt-bearing nature of the parent materials, human intervention also contributes to anthropogenic salinization processes as: 1) deforestation caused saline seepage and consequently salinization over a wide area, 2) reservoir construction in potential salt source, 3) utilization of low quality irrigation water with inefficient or inadequate drainage causes rapid man-made salinization, and 4) salt-making. The process of salt-making includes the pumping of saline groundwater (50-60 dS m^{-1}) from a depth of about 20 m, or dissolved brine from a rock salt bed, and flooding the soil surface. Saline water will evaporate, leaving the salt behind. This causes adjacent and downstream lands to become saline.

Saline groundwater is one of the factors that affects the development of salinity. In the northeast of Thailand, salt sources also occur in brine springs, seeps and wells. Wells drilled deeper than 20 m are likely to encounter highly saline water (Piancharoen, 1973). This deeper saline groundwater is well below the range of capillary movement, but it is commonly artesian (Haworth, *et al*., 1966).

In localized areas, a shallow saline groundwater may be formed by the groundwater flowing through a shallow salt dome, and moving up from a depth below 10 to 15 m by hydrostatic pressure, particularly where pronounced permeability or sloping terrain give a good head of water (Tuckson, *et al*., 1982). In some areas salts are derived from shallow groundwater that is 1-2 m below the soil surface, allowing salt accumulation and the formation of a salt crust on the surface of the soil through evapotranspiration.

In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop, at a higher concentration than in the applied water. The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage. If salt become excessive, losses in yield will result (Ayers and Westcot, 1985). Quality of irrigation water is shown in **table 1.1.**

Table 1.1 Evaluation of water quality for irrigation (Ayers and Westcot, 1985).

Salinity	**Units**	**Degree of restriction on use**		
		None	**Slight to moderate**	**Severe**
EC_w	$dS\ m^{-1}$	>0.7	0.7-3.0	>3.0
TDS	$mg\ l^{-1}$	<450	450-2000	>2000
Na	%	<3	3-9	>9

1.2.5 Appearance of saline soil and salinity effect on plant

In the field, saline soils can be recognized by the spotty growth of crops, while white salt crusts occur on the surface. Excess soil salinity causes poor and spotty stands of crops, uneven and stunted growth and poor yields, the extent depending on the degree of salinity. When the salt problem is only mild, growing plants often have a blue-green tinge. Barren spots and stunted plants may appear in cereal or forage crops growing. The extent and frequency of bare spots is often an indication of the concentration of salts in the soil (Abrol *et al*., 1988).

In some areas, as in Australia, changing the type of vegetation has resulted in a rising water table and dryland salinity has occurred (Munns, 2002)

Salinity adversely influences plant growth, leading to significant reductions in yield and degraded agricultural productivity. The degree of damage depends on species, variety, growth stage and environmental factors. Salinity effects on plants include impeded water uptake, imbalance of plant nutrients and accumulation of toxic ions (Luttge *et al.*, 1984; Sharma, 1984).

Moderate salinity however, particularly if it tends to be uniform throughout the field, can often go undetected because it causes no apparent injuries other than restricted growth. Leaves of plants growing in saline areas may be smaller and darker blue-green in color than the normal leaves. Increased succulence often results from salinity, particularly if the concentration of chloride ions in the soil solution is high. The characteristics of plants in salt-affected soils often have the same appearance as plants growing under moisture stress. The wilting of plants is far less prevalent because the osmotic potential of the soil solution usually changes gradually, and plants adjust their internal salt content sufficiently to maintain life and avoid wilting (Abrol *et al*., 1988).

1.2.6 Mechanism of tolerance in plants

Many plants have developed special mechanisms to avoid or tolerate salinity effects. These mechanisms were described by Flowers (1975); Greenway and Munns (1980);

Ayers and Westcot (1985) and Cheeseman (1988) as follows.

a) Transportation or movement of salt to accumulate in vacuole.

b) Maintainance of salt balance by excretion of the absorbed salts.

c) Building enzymes that tolerate a high concentration of salt.

d) Adjustment in osmotic pressure by increasing internal osmotic pressure.

e) Salt exclusion or avoidance by selective ion absorption of cell membrane.

f) Increasing succulence in cells, which results in lower salt concentration in plant cells.

g) Plant leaves produce wax and the wax coated leaves lower transpiration.

h) Immobilisation with in plant; plants immobilise the absorbed salts by storing them in special structure.

Rating of salt tolerance is based on reduction of yield in saline conditions when compared with yield on non saline soil. Generally recognized soil salinity classes and their effect on crop plants are given in **table 1.2**.

1.2.7 Management of saline soil

Due to the increasing trend of population, food requirements are increasing rapidly and it is necessary to increase crop production. Saline agriculture is an alternative strategy to solve this problem (Ladeiro, 2012). However, management depends upon the degree of salinity and location-specific salinization processes. Management and remediation of salt-affected soils are highly problematic. In general, recommended strategies include leaching, land leveling, surface mulching, application of organic amendments, deep plowing and utilization of salt tolerant varieties (Pongwichian *et al.*, 2013; Arunin and Pongwichian, 2015). Unproductive saline soils can be made fit for agricultural production. First, the soluble salts must be removed from the root zone and the source of salts cut to prevent resalinization of the soils. The common techniques for management of saline soils are as follows.

Table 1.2 Criteria for classifying salinity of soils and crops growth.

Soil Salinity Classes	Conductivity of the Saturation Extract ($dS\ m^{-1}$)	Salt Percentage (%)	Effect on Crops
Non saline	0 - 2	< 0.10	Salinity effects negligible
Slightly saline	2 - 4	0.10 - 0.20	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	0.20 - 0.40	Yields of many crops are restricted
Highly saline	8 - 16	0.40 - 0.80	Only tolerant crops yield satisfactorily
Very highly saline	> 16	> 0.80	Only a few very tolerant crops yield satisfactorily

Source: Adapted from Abrol *et al*. (1988)

a) Salt leaching

Excess salt can be removed from the root zone to improve crop growth. The common methods used to remove soluble salts from the root zone (DESCONAP, 1990) are described as follows:

- Scalping: The salt crust from the soil surface can be removed mechanically. This might temporarily improve crop growth, but the ultimate disposal of salt remains the major problem.

- Flushing: Surface concentrated salt can sometimes be washed away by horizontal flushing, provided a drain or some low-lying waste area is available nearby.

- Leaching: Leaching is the process of dissolving and transporting soluble salt from the root zone by the downward movement of water through the soil.

b) Organic matter management

The productivity of saline soils can be improved by organic matter management to provide adequate nutrients, together with proper tillage practices. In saline soil, the formation of sodium-organic matter complexes contributes to a higher solubility of the organic matter, which can be rapidly leached from the soil, consequently causing the soil to become infertile and unproductive. Because of the importance of soil organic matter as a source of nutrients, organic matter supply assures a sustainable productive soil, and acts as a soil conditioner and buffer.

Soil organic matter governs physico-chemical and biological properties of soils. Thus addition of organic matter to soil containing low levels of organic matter will improve the soil's physical properties as evidenced by increased water content, increased water retention, enhanced aggregation, increased soil aeration, greater permeability, increased water infiltration, and decreased surface crusting (Parr, *et al.*, 1978).

c) Green manuring

Green manuring is defined as plant material incorporated into the soil while still green, or soon after maturity, for soil improvement (Soil Science Society of America, 1965). Green manure crops can be leguminous as well as non-leguminous. Palaniappan and Budhar (1992) report that green manure is suitable for managing salt-affected soils, as a source of plant nutrients, and to supply energy to soil microorganisms. Application of green manure can improve soil physical properties such as texture and bulk density. These result in increasing exchangeable Na^+ leaching capacity. Due to the increase in the price of chemical fertilizer and its environmental effects, the use of organic fertilizer has become feasible and more extensive, with more attention being given to green manuring in particular. Organic fertilizers include compost, farm yard manure and green manure, as N-sources. Residual effects on salinity and acidity are found after extended use of fertilizer. Some chemical fertilizer, especially N fertilizer, has poor efficiency and high

N loss. An organic N source such as green manuring is a cheap nitrogen source to increase crop yield and improve soil fertility. It is well recognized that legume crops grown in a cropping system will increase growth and yield of the main crop. Nutrients such as N, P, K, Ca, Mg and micronutrients will be released after incorporation. Utilization of green manure results in increase adsorption capacity and nutrient availability, and improved soil physical properties (Ladha *et al*., 1988; Roger and Watanabe, 1986). However, suitable species of green manure varied with agro-climatic, soil and water conditions, for example green manure planted in saline soil must be tolerant of salinity and also to acidity and water logging. Numerous studies indicate that one leguminous plant, namely *Sesbania rostrata*, shows high potential as a green manure crop in saline soils for rainfed lowland rice systems in Thailand (Arunin *et al*., 1987a; 1988; 1992a; 1994; Anuluxtipun *et al*., 1992; Pongwichian *et al*., 1997; 1998; 2006 and Thamphang, 1992).

d) Biological management

Besides agronomic management, biological processes can improve and reclaim slightly and moderately saline soil. It has been found that some groups of microorganism can fix or induce the formation of plant nutrients and then change them to an available form for crop growth. These salt tolerant microorganisms inhabit plant root systems in saline soil, especially the roots of rice. They are classified as aerobic halophilic bacteria (Tilak *et al*., 2005) namely *Halomonas* sp., *Flavobacterium* sp., *Halobacillus* sp, *Bacillus pumilus* and *Bacillus firmus*. The other free living bacteria that are found in root systems are *Pantora*, *Citrobacter*, *Microbacterium* and *Stenotrophomonas*.

e) Chemical management

Due to saline soil having poor physical properties and an excessive of Na^+, it is necessary to improve physical properties and remove Na^+ from the soil. The most common amendment is gypsum. In saline conditions (high Na^+ concentration), dispersion is found. This restrains plant growth and soil physical properties should be improved. Numerous studies showed that using gypsum as an amendment is a solution for this problem. Gypsum application resulted in decreasing dispersion ratio, while hydraulic conductivity, water infiltration and aggregate stability increased (Sharma, 1971; Sharma *et al*., 1982).

f) Engineering management

Leaching and drainage, are effective methods in the reclamation of severely saline soils but these techniques require high investment. The system is generally only feasible as a large-scale government initiative, as the farmers or land owners cannot do it by themselves. For example, the polder system comprises canals and perimeter embankments to control levels of ground and surface water and subsequently control salinity hazard in the system by manipulating groundwater levels. The other engineering methods are open and sub-surface drainage which can be effective in leaching and drainage of saline groundwater in severely saline soils.

g) Salt tolerant crops and halophytes

Severely saline inland soils are typically considered as waste land, however they can be rehabilitated. Engineering and chemical methods have been implemented in many regions but they are not successful due to high energy requirement, high investment cost, management difficulties, etc. Utilization of salt tolerant species and varieties is recommended. Some salt tolerant crops and halophytes that are commonly used include *Sporobolus virginicus* [both coarse type (Dixie grass) and smooth type (Smyrna grass)], *Spartina patens*, *Distichlis spicata*, *Atriplex* species and Kallar grass (*Leptochloa fusca*) etc. For example, the exotic halophytes, namely *Sporobolus virginicus* [both coarse type (Dixie grass) and smooth type (Smyrna grass)], *Spartina patens* and *Distichlis spicata* could survive in severely salt-affected soils of Thailand (Yuvaniyama and Arunin, 1992a). The mechanisms of their tolerant ability include osmotic adjustment within the plant, excretion of salt by roots, water storage in tissues, salt exclusion or avoidance, ion accumulation and sequestration, excretion of salt via glands in plant leaves or stem and immobilisation within the plants (Flowers, 1975; Gallagher, 1979; 1985). However, tolerance levels depend on the kind and amount of salt, stage of plant growth, plant species and environmental factors.

Ladeiro (2012) reported that these halophyte plants have the capacity to grow using land and water unsuitable for conventional crops; producing food, fuel, fodder, fibre, resin, essential oils, and pharmaceutical products. In addition to their production capabilities they can be used simultaneously for landscape reintegration and soil rehabilitation. Some of them had economical potential as sources of oils, flavours, gums, resins, pharmaceuticals, and fibres (Galvani, 2007), or with environmental potential for protection and conservation of ecosystems (e.g., improvement of soil structure and fertility, habitat for wildlife, source of biomass for the production of biodiesel) (Barnes and Baylor, 1995; Zhang *et al*., 2007).

Saline soil is one of the main agricultural problem soils of Thailand. It results in decreasing crop yields, especially rice yields in northeast Thailand, so the appropriate solutions should be considered quickly with community participation.

1.3 Importance of agronomic management of saline soil in agricultural land

Salinity causes major problems in farmer's soils and crops and remediation and management practices are required. The problems of salt-affected soils are long standing and they reduce soil productivity. Salinity adversely influences plant growth, leading to significant reductions in yield and degraded agricultural productivity. For saline soil in the northeast of Thailand, fertility is very low due to the coarse soil texture and the leaching of nutrients that encourages very low organic matter content in the soil. N–deficiency in plants becomes more serious in saline soil than that in normal soil. Remediation of this problem is needed. Abrol *et al*. (1988) reported that the general characteristics and basic principles involved in the identification, reclamation and management of salt-affected soils are the same throughout the world. However, differences from place to place in soil characteristics, climate, water availability, farm management capability, financial resources, available inputs and economic incentives lead to differences in method, extent and rapidity of soil reclamation. Although technical literature abounds with sound information on the subject, nonetheless, there are far too many partial or complete failures of efforts to reclaim salt-affected soils. These failures were due to lack of proper identification and subsequent use of incorrect reclamation methods, resulting in losses of both money and potential increases in crop production.

Depending on the degree of salinity and the specific salinization process, the management and remediation of salt-affected soils may be approached through agronomic management, biological/chemical management and engineering management.

a) Agronomic management is a cultivation advance for farmers which includes farm management systems to improve soil quality, selection of plant varieties, enhanced water use, management of crop residues and better fertilizer management. For saline soil in Thailand agronomic management can be separated into:

- Agronomic management of slightly and moderately saline inland soil (appropriate agronomic management for increasing rice yields and salt tolerant crops such as asparagus, tomato, garlic, chives, cantaloupe, broccoli and Chinese kale can be grown combined with agronomic managements)

- Agronomic management of severely saline inland soils (utilization of salt tolerant species and varieties are recommended)

- Agronomic management of coastal saline soils (salt-tolerant rice varieties with organic amendments and chemical fertilizer application are recommended and salt tolerant crops are used for land rehabilitation)

- Agronomic management of central plain saline soils (selection of salt-tolerant varieties, mulching, application of organic amendments as green manure, compost, farmyard manure and drip irrigation are recommended)

b) Biological/chemical management. Biological process can improve and reclaim slightly and moderately saline soil. It has been found that one particular group of microorganisms, classified as aerobic halophilic bacteria, can be beneficial. For chemical management, gypsum is a suitable amendment for the solution of this problem.

c) Engineering management for reclamation of severely saline soils. Methods are open and sub-surface drainage, but this system is generally only feasible as a large-scale project through government initiatives.

From data from the three management systems that are mentioned above, it can be summarized that agronomic management is suitable for farmers who have salinity problems in Thailand. Singh *et al*. (2014) summarized that agronomic management is the most important input for getting potential yield and high net returns in any crop or crop sequence. The findings of the present study envisage that for feeding the ever growing population and to earn higher returns, farmers should adopt the recommended management practices for rice-wheat cropping system. The management practices increased productivity and ultimately the returns from each incremental change, with the recommendation that adoption of some of the practices would result in increased yields and returns. However, the resource poor and marginal farmers who cannot afford to adopt the full package of recommended management practices should go for as many management practices as they can afford, particularly improved varieties, proper spacing, and recommended fertilization. However Hussain *et al*. (2001) reported that amendments are costly inputs and sometimes are not affordable by poor farmers. Minimum input, or at least split fertlizer application should be considered also.

For the poor farmer in saline areas of Northeast Thailand, living on soils unsuitable for cultivation, a low yielding crop could not cover the cost of farm investment and would result in insufficient food for self-support. Special farm management or cultivation practices and soil and water management are needed for rice production on slight and moderately saline soils. The recommended management techniques should be cheaper, oriented to the existing cropping system and be easily adapted by the farmers. However engineering management systems, due to high investment requirement, is generally only feasible on a large-scale through government initiatives. Farmers can still see significant increases in yield and improved quality of the land through agronomic practices.

Farmers in saline areas have adapted, for example in rainfed non–irrigated areas of northeast Thailand, where rain water is the only source available to be used for leaching saline soils. Planting is recommended to be delayed until early rains have reduced the salt content of the soil (Arunin, 1984; Yuvaniyama, 1994b).

This is a successful agronomic management for rice cultivation in saline soil. Slightly to moderately salt-affected soils are typically used for rice cultivation (Arunin, 1984) due to rice being a moderately salt tolerant plant (Alphen, 1983). Arunin (1992) recommends appropriate agronomic management for increasing rice yields; these include selection of KDML 105, a highly salt-tolerant rice variety, transplanting of seedlings at thirty to thirty-five days old, closer spacing of 15x20 cm, with an increased number of seedlings (6-8 seedlings per hill) and application of organic soil amendments such as green manure (*Sesbania rostrata*), farmyard manure and compost to increase soil fertility and improve physical properties of soil.

The other example is for areas that are not prone to flooding, where slightly and moderately saline soils may also be used for cultivation of cash crops. Cash crops which are tolerant to salinity such as asparagus, tomato, Chinese radish, Chinese kale, cantaloupe and safflower. However, studies show that special agronomic management and water management are needed, including use of salt-tolerant varieties, suitable land preparation, mulching, organic amendment application (green manure, compost, farmyard manure) and appropriate irrigation.

So it can be summarized that from the perspectives of cost-performance, natural environment and the country’s farmers’ capacity, agronomic management serves in the best interests of Thailand.

Chapter 2

Soil and agriculture in Thailand

2.1 Basic information on Thailand

Thailand is located in Southeast Asia and situated between latitude of 5-21^0 N and longitude of 98-106^0 E. It borders Laos and Myanmar to the north, Cambodia to the east, Myanmar to the west and Myanmar and Malaysia to the south. The total land area is 51.31 million hectares (million ha). Agricultural land is 23.878 million ha.

The climate of Thailand is classified as tropical. The country's geographical position impacts on the climate. There are two monsoons: the southwest monsoon which carries moisture from the Indian Ocean (mid May to September) and the northeast monsoon which brings in dry and cold air from China (November to mid March). Highest maximum temperature normally occurs in April while the lowest minimum temperature occurs in December and January.

The population of Thailand is 65,124,714 (5 March 2015), with an annual growth rate of 1.3 percent. Population density is 127 persons per square kilometer. The distribution of the population varies but is mostly concentrated in the plain around Bangkok, the capital city, and also surrounding the other large cities.

2.1.1 Physiographic regions and geomorphology

There are six regions recognizable by their characteristic land forms, the Northern ranges and Valleys, the Central Plain, the Western Mountains, the Southeast Coast, the Northeast Plateau or Khorat Plain, and the Southern Peninsula (Moncharoen *et al.*, 1987; Vijarnsorn and Eswaran, 2002).

a) The Northern Ranges and Valleys occupy the area above 18^o N latitude. The forest cover is still closer to 50 percent of the land area, the best in all the regions. The North may not have the heaviest rainfall in the country, but with its physical landforms and good forest cover, the soil water is high and the soil productivity continues to be above average for the country.

b) The Central Plain extends southward from the ranges and valleys of the North to the Gulf of Thailand. It encompasses the alluvial plain of the Chao Phraya River with its many tributaries, and the surrounding piedmont belts. The plain has a deep, fertile soil deposited by water from the North and also from the mountains on its western and eastern boundaries.

The upper plain and marginal plains: For political reasons, this area is the lower part of the administrative Northern region. The marginal plains consist of a narrower strip of piedmont plains to the west and east. They share the following common land forms: narrow plains of deposition along the rivers, low rock outcrops and higher elevation than the lower plain. The soil is fertile, but shallower.

The lower plain, Bangkok Plain or Deltaic Plain: This plain is a true plain of aggradation, with deep soil formed by alluviation, and is slowly extending seawards through deposition of waterborne sediments into the Gulf. The Chao Phraya River branches at about 15^{o} 15'N latitude to give rise to the Nakhon Chaisri River that runs in parallel with it to the Gulf.

c) The western mountains represent a continuation of the Central Cordillera from the north, between Thailand and Myanmar, to the west of the Central Plain.

d) The Southeast coast or East coast of the Gulf of Thailand is a rolling land with low hills to its north and mountains to its east, and with narrow coastal plains. The mountains and hills to the east are effective in trapping rainwater from the southwest monsoon, giving the southeast corner strip precipitation of over 4,000 millimeters.

e) The Northeast Plateau, or Khorat Plain, the Northeast's major river system is the Mun, which drains into the Mekong. Flooding during the wet season is normal, due to very slow river flows, and to high water from the Mekong itself. During the dry season, many localities will develop a salt crust, following the evaporation of saline water brought up through capillary action from deeper layers, especially in a shallow sandy soil over rock salt.

f) The Southern Peninsula is a continuation of the western mountains, affording a number of basins, and river and coastal plains which are fertile and habitable.

2.1.2 Natural vegetation

The natural vegetation refers to the natural forest which in general, defines a community of living trees and associated organisms; covering a considerable area; utilizing sunshine, air, water, and earth materials to attain maturity and reproduce itself; and capable of furnishing mankind with indispensable products and services (Vijarnsorn and Eswaran, 2002). The forest types are influenced by local climatic conditions, in turn resulting in the development of two main categories of forest type, the evergreen and the deciduous.

a) The evergreen forest forms about 60 percent of the total forest area. It can be subdivided into four types;

- The tropical evergreen forest occurs along the wet belt of the country, where high amounts of rainfall, over 1,500 mm, are prevalent, and is affected by the monsoon. The principal trees are mostly *Dipterocarps*, oaks and chestnuts.
- The coniferous forest occurs in small pockets in the northwestern highland and the Korat Plateau.
- The swamp forest occupies the areas which are more or less subjected to occasional inundation, and is scattered in the wet region of the country.
- The beach forest occurs in the areas along the beach, where sand dunes, rocky seashores and elevated seacoasts are prevalent.

b) The deciduous forest occupies the dry belt of the country, where precipitation is lower than 1,000 mm. The vegetation of these zones is classified as deciduous. Deciduous forests can be subdivided into three main categories: The mixed deciduous, the dry *Dipterocarp* and the savanna forests.

2.1.3 Agriculture in Thailand

Thailand is regarded as an agricultural country. The agricultural sector has played an important role in the growth of the economy throughout Thai history from the Sukhothai period (1277-1350), based on small-scale agriculture. From past to present, the subsistence agricultural system has gradually changed and developed into a more commercial system. The real boost in agricultural production came after the launching of the First National Economic and Social Development plan (1961-1966) when the agricultural sector was diversified into economic crops, horticulture, livestock, and fishery. Agriculture has been given high priority for development in all eight National Economic and Social Development plans.

The production of commercial crops in Thailand is highly diversified. It includes cereal crops, field crops, perennials, fruit trees, vegetables, herbs, cut flowers, and ornamental plants. Rice is the country's most important crop with Thailand being a major exporter in the world rice market. Recently, the government approved a strategic plan to boost competitiveness of 12 key export commodities. Except for black tiger prawns, these commodities are all crops, including rice, maize, cassava, para rubber, sugarcane, coffee, oil palm, longan, pineapple, durian, and orchids (http://www.moac.go.th/eng/#).

Thailand has global leadership in the production and export of a number of agricultural commodities. There still remains potential for further large increases in productivity from known technologies. Thailand leads the world in producing and exporting rice, rubber and canned pineapple. In the last few years, Thailand is the only country in the Asia region that has had a surplus of food for export for a long period of time - more than 20 consecutive years. Now, however, agriculture tends to decline. Uncertainty of income may be an important cause. Furthermore, technical and economic globalization forces have continued to change agriculture into a food industry (Falvey, 2000). However, intensive integrated production systems of subsistence farming have continued to offer efficiencies that are not financial, including social benefits which have now caused agriculture to be treated as both a social and financial sector in planning, with increased recognition of environmental and cultural values.

2.1.4 Agricultural resources

Agricultural resources can be divided into two categories: arable land and water.

a) Arable Land: The total area of the country is 513,115 km^2, of which 54 percent or 27,888,966 ha is devoted to agriculture. The latest survey shows that land under cultivation includes 24.0 percent for rice production, 12.7 percent for field crops, and 11.4 percent for perennial crops (Land Development Department, 2015). Although agricultural production has increased significantly, increased production largely was due to the expansion of cultivated land through forest encroachment rather than increasing yield per unit area. The soil has been repeatedly cultivated without proper attention to improve its conditions, resulting in a decline in fertility. As a result land development policies are placing increased emphasis on the improvement of soil productivity, soil conservation, and land reform.

b) Water**:** Rainfall is the most important source of water in agriculture, with approximately 80 percent of all agricultural land producing under rain fed conditions. The Royal Irrigation Department reported that there are small areas in developed irrigation of 4.478 million ha or approximately 20 percent of agricultural land (**Table 2.1 and 2.2**). The northeastern part of Thailand, in particular, has the lowest percentage of developed irrigation area (http://information.rid.go.th/prd/document/2_1.pdf). This results in lower agricultural production. Water resources are managed as follows:

- Groundwater resource management: This water resource can be found throughout the country. The development of groundwater is limited, based on the hydro-geological structure of some areas, depending on the presence of salt deposits, minimal water reserve, or poor water quality. Utilization of ground water has a high cost and it may not be profitable when applied extensively to agricultural production.

Table 2.1 Land utilization and water resources development of Thailand in 2006.

Land use development	Area (ha)
1. Total land areas	51,311,502
2. Farm holding land	22,368,019
3. Potential area for irrigation development	9,647,079
4. Irrigated land	4,478,138

Table 2.2 Irrigated areas of Thailand by region in 2006 (ha).

Region	Potential area	Irrigated land
Northern	1,655,339.0	809,641.6
North-Eastern	4,519,732.0	986,037.4
Central Plain	1,781,990.0	1,752,060.0
Eastern	803,772.3	405,841.1
Southern	886,245.4	524,558.1
Total	9,647,079.0	4,478,138.0

- Surface water resource management: This includes development of dams, weirs, and reservoirs, including the development of ponds, canals, lakes, and rivers to increase water-holding capacity.

- Atmospheric water resource management: Apart from natural rain, the management of atmospheric resources, or in other words, artificial rain is the only way to add water to surface and groundwater resources. The “Royal Rainmaking” initiative is one of His Majesty the King’s projects that date back to 1969.

2.1.5 Forests

Forest resources in Thailand can be classified into five types: Evergreen forest, mixed deciduous forest, dry *Dipterocarp* forest, pine forest, and mangrove forest. Of these, the dominant type of evergreen forest is tropical rainforest, covering 43 percent of the total forest area. Its concentration lies in the highest rainfall zone (http://www.moac.go.th/eng/#).

2.2 Soil resources

There are many kinds of soils in Thailand which differ in thickness, texture, drainage capacity, fertility, degree of flooding and in many other ways. These properties are caused by interaction between climate, parent material, relief and living organism. Most soils in the low-lying areas are placed in the great groups of Sulfaquents, Hydraquents, Endoaquents, Dystraquerts, Natraqualfs, Endoaquerts, Endoaquepts, Paleaquults, Endoaqualfs and Haplofibrists. Most soils in the Northeast Plateau, Central Highlands, North and West are classified as soils with a ustic moisture regime. They are included in the great groups of Ustifluvents, Paleustalfs, Hapstalfs, Kandiustox, Haplusterts, Haplustolls, Haplustults and Paleustults (Vijarnsorn and Eswaran, 2002).

Based on the soil resources data, the Land Development Department (2015) established a soil map of Thailand as shown in **figure 2.1.** The map can be divided into 6 mapping units, as follows;

2.2.1 Lowland soils or soils with aquic condition

These soils are commonly saturated by groundwater or by water of the capillary fringe. They are classified as poorly drained soils, in the low - lying terrain of Thailand, which are mostly cultivated into wetland rice. Most of the soils in the coastal low-lying terrain commonly occur on the tidal flat areas, which are frequently inundated by seawater and occupied by mangrove forest, and the dominant characteristics of these soils are the muddy clayey horizons (immature soils). Inland soils are patchily distributed in the areas which are affected by salt as a result of geomorphological phenomena.

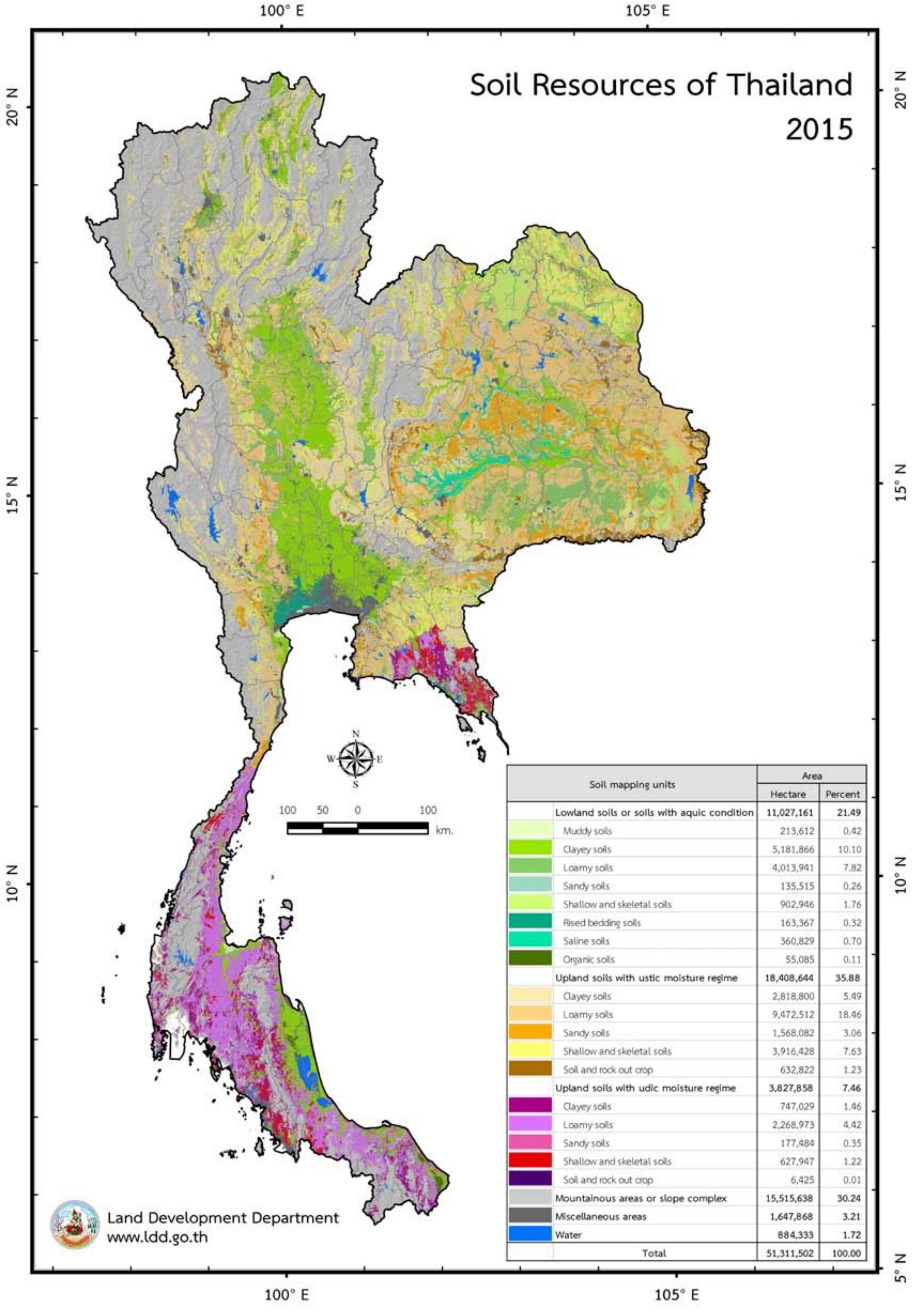


Figure 2.1 Soil resources of Thailand

The exchangeable sodium percentage (ESP) of these soils commonly exceeds 15%. Peat and muck soils are located in the swamp areas. Clayey and loamy soils predominantly occur in flood plains, alluvial plains, coastal plains and alluvial terraces or fans, while sandy or skeletal soils occur mainly on the low-lying alluvial terraces.

2.2.2. Upland soils with ustic moisture regime

These are soils which are dry in some parts or all parts for 90 or more cumulative days in most years. Included are most of the upland soils in the Northeast Plateau, Central Highland, North and West used for agriculture. The landforms of the areas can be divided into flood plain, alluvial plain, alluvial terraces fan or erosional surfaces. The soils have developed from alluvial deposits and weathered rock. The ground water table is deeper than 2 meters in the dry seasons. The drainage pattern is classified as moderately well drained, well drained or somewhat excessively drained. The soil texture is classified as sandy, loamy or clayey. Shallow soils accompanied by soil and rock which are still under native forest or shrub are deemed to be unsuitable for plant growth because of rock or stone situated on the soil surface.

2.2.3 Upland soils with udic moisture regime

Most of the upland soils on the Peninsula and the southeast coast of Thailand have an udic moisture regime. They are not dry in any part of the control section for 90 days (cumulative). Landform of the areas can be divided into flood plain, sandy beach, alluvial plain, alluvial terraces or erosional surfaces. The soils have developed from alluvial deposits and weathered rock. Tropical karst topography predominates in the limestone and surrounding areas. The sandy textured soils that occur on beach ridges along the coastline are deep and somewhat excessively drained. The remaining areas were classified into loamy or clayey soil textures with moderately well drained or well drained profiles, and shallow soils with rock fragments, lateritic ironstone layers, bed rocks or cobble stones often found at a depth less than 50 cm below the surface. These areas are unsuitable for agriculture. They were recommended for reforestation to preserve the environment. All of the upland soils on the Peninsula and the southeast coast are low in CEC, of low fertility, highly leached, of low pH and contain mainly kaolinite.

2.2.4 Mountainous area or slope complex

Soils of the mountainous area or slope complex are developed from the residuum and colluvium of various rocks such as igneous sedimentary and metamorphic rocks. The areas occur in the terrain where slopes are steeper than 35%.

2.2.5 Miscellaneous areas

Miscellaneous areas have essentially no soil and support little or no vegetation. The causes are soil erosion, run off by water, unfavorable soil conditions, or man's activities.

2.2.6 Water

Water includes river streams, lakes, ponds, and estuaries that in most years are covered with water at least during the period warm enough for plants to grow; many areas are covered throughout the year.

2.3 Present status of land use

In assessing the land use of Thailand, Vijarnsorn and Eswaran (2002) observed that the lower flood plains are used primarily for rice cultivation (direct-seeding of floating rice), while the higher-elevation flood plains and lower terraces are more suited to transplanted rice. Higher altitude terraces, plateaux and foothills support upland crops, grazing, shrubs and trees (for food and fibre). Land Development Department (2015) reported that during 2010-2013 it surveyed and assessed the land use of Thailand by using Satellite Imagery. The land resources of Thailand can be divided into 5 types of land use, namely urban and built-up land, agricultural land, forest land, water body and miscellaneous land which cover areas of 2.643, 27.889, 17.482, 1.437 and 1.860 million ha, respectively.

For agricultural land, 27.889 million ha or 54.36 percent of the total land area is used for paddy, field crops (sugar cane, cassava and maize), perennial crop, orchard, shifting cultivation, aquacultural land and other agricultural land (pasture, farm house, horticulture), which cover areas of 12.337, 6.514, 5.829, 1.796, 0.646, 0.465 and 0.30 million ha, respectively as shown in **figure 2.2 and table 2.3**.

The change in land use in Thailand during 2006 to 2013 showed that urban and built-up land, agricultural land, water body and miscellaneous land tended to increase while forest land decreased (Land Development Department, 2015). The increasing trend of population results in the need of land for household agriculture. The price of agricultural products is a factor in land use change. For agricultural land the price has generally increased, but that of paddy field has tended to decrease. There are two main factors that impact on land use change; physical factors and socio-economic factors. Physical factors included soil type, geography, irrigation and agricultural factory area. Socio-economic factors include size of population, government policy, product price and market.

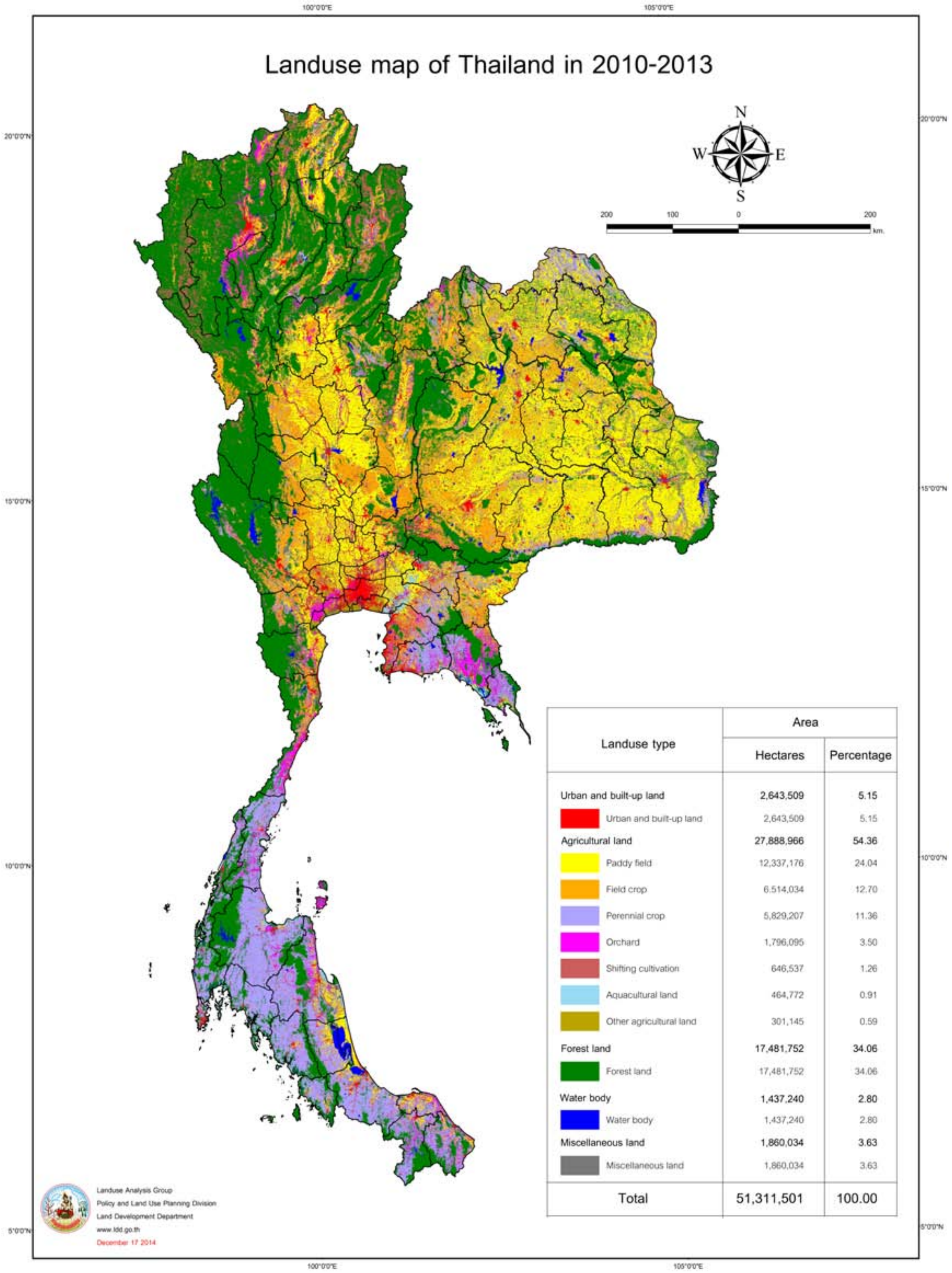


Figure 2.2 Landuse map of Thailand in 2010-2013.

Table 2.3 Landuse of Thailand classified by Land Development Department in 2010-2013.

Landuse type	Area	
	Hectare	Percentage
Urban and built-up land	**2,643,509**	**5.15**
- City, Town, Commercial	274,816	0.54
- Village	1,641,102	3.20
- Other	727,591	1.41
Agricultural land	**27,888,966**	**54.36**
Paddy field	12,337,176	24.04
Field crop	6,514,034	12.70
Perennial crop	5,829,207	11.36
Orchard	1,796,095	3.50
Shifting cultivation	646,537	1.26
Aquacultural land	464,772	0.91
Other agricultural land	301,145	0.59
- Pasture and farm house	150,964	0.29
- Horticulture	157,685	0.31
- Other	7,504	0.01
Forest land	**17,481,752**	**34.06**
Water body	**1,437,240**	**2.80**
Miscellaneous land	**1,860,034**	**3.63**
- Salt flat	8,894	0.02
- Rock out crop	62,846	0.12
- Other	1,788,294	3.49
Total	**51,311,501**	**100.00**

Beside the report of The Land Development Department (2015) about the statistics of land use, the Office of Agricultural Economics (OAE) (2014) reported that agricultural land in 2013 was approximately 23.877 million ha which was used for paddy, field crops, fruit trees, vegetables and other of 11.19, 4.98, 5.59, 0.22 and 1.89 million ha, respectively (**Table 2.4**). Therefore agricultural land use is widespread in Thailand. And it also is found that the soil has been repeatedly cultivated without proper attention to improve its conditions, resulting in a decline in fertility. So land development policies now emphasized the improvement of soil productivity, soil conservation, and land reform (http://www.moac.go.th/eng/#). The change in land use in Thailand 1986-2013 is shown in **table 2.5**. The data show that paddy land and field crop tended to decrease while the land used for fruit tree, vegetable and other tended to increase.

Table 2.4 Farm holding land of Thailand by region, 2013 (ha).

Regions	Farm holding area	Paddy land	Field crop	Fruit tree	vegetable	Other
Whole Kingdom	23,877,797	11,194,378	4,984,640	5,586,444	223,741.3	1,888,594
Northern	5,198,348	2,526,018	1,631,406	647,283	71,511	322,130
North-Eastern	10,215,639	6,840,387	1,910,548	690,494	50,772	723,437
Central Plain	4,980,865	1,632,143	1,441,023	1,183,047	81,093	643,560
Southern	3,482,945	195,829	1,662	3,065,621	20,365	199,468

Table 2.5 Change in agricultural land use in Thailand 1986-2013 (ha).

Years	Farm holding area	Paddy field	Field crop	Fruit tree	Vegetable	Other
1986	20,943,830	11,875,808	5,235,866	2,291,837	86,216	381,292
1987	20,992,420	11,547,067	5,353,213	2,559,919	120,553	341,753
1988	21,083,641	11,332,426	5,318,548	2,840,802	120,132	340,195
1989	21,092,990	11,230,381	5,302,050	2,968,023	113,397	325,610
1990	21,139,905	11,109,777	5,346,432	3,108,607	128,936	319,534
1991	21,292,190	11,080,499	5,361,748	3,240,939	137,309	349,255
1992	21,128,193	11,013,699	5,247,202	3,335,915	141,076	305,304
1993	21,003,343	10,933,851	5,156,500	3,359,824	148,986	330,752
1994	21,093,326	10,931,304	5,140,883	3,462,148	150,046	344,213
1995	21,196,571	10,926,840	5,121,790	3,571,039	153,269	386,028
1996	21,091,121	10,807,289	4,979,166	3,701,018	153,524	431,799
1997	20,977,217	10,671,352	4,816,193	3,861,125	153,789	475,052
1998	20,862,964	10,546,250	4,648,314	4,012,705	153,788	514,276
1999	21,014,621	10,509,919	4,605,840	4,172,079	164,130	538,594
2000	20,991,346	10,466,010	4,565,662	4,216,146	174,562	551,822
2001	20,969,596	10,435,294	4,518,664	4,253,471	184,459	581,783
2005	20,844,159	10,217,771	4,384,068	4,446,076	196,769	424,489
2006	20,846,515	10,168,180	4,359,995	4,580,263	197,910	962,567
2007	20,856,529	10,220,394	4,259,059	4,649,820	194,537	944,237
2008	21,085,707	10,487,078	4,507,009	4,500,971	177,091	839,870
2009	21,055,286	10,572,424	4,371,972	4,384,006	190,879	929,129
2010	23,906,669	11,244,481	5,007,527	5,554,796	217,284	1,882,580
2011	23,879,428	11,197,705	4,983,901	5,585,189	223,149	1,889,483
2012	23,878,409	11,194,876	4,984,781	5,586,338	223,546	1,888,868
2013	23,877,797	11,194,378	4,984,640	5,586,444	223,741	1,888,594

2.4 Agricultural problem soils of Thailand

Thailand is regarded as an agricultural country, with agricultural land area being more than 40 percent of total land area. However, problems of land resources are found.

“Agricultural problem soil” is not an exactly determined concept and creates some inherent problems of definition. A problem soil is related to a specific land use situation. Generally, agricultural problem soils include acid soils, calcareous soils, Histosols (peat soils), salt affected soils (saline and sodic soils), sandy soils, steeplands and Vertisols (http://www.fao.org/ag/AGL/agll/prosoil/ psintro.htm). The lands of Thailand have many agricultural problem soils such as organic soils, extreme acid sulfate affected soils, salt affected soils, shallow soils, sandy soils, acid soil, and steeplands. These problem soils affect plant growth, however, the response varies with soil type and plants. Agricultural problem soils cover an area of 43,320,022 ha as shown in **table 2.6** (Office of Soil Survey and Land Use Planning, 2006).

Table 2.6 Agricultural problem soils in Thailand (ha).

Soil types	Area
Organic soil	42,456
Acid sulfate soil	881,623
Saline soil	2,302,955
Shallow soil	6,938,499
Sandy soil	2,043,173
Acid soil	15,749,199
Steeplands	15,361,117
Total	43,320,022

However, the distribution of agricultural problem soils depends on location, parent material, climate and topography as shown in **table 2.7**. For example, in the North-eastern part of Thailand, acid soils cover a greater area than shallow soils and saline soil, respectively. While in the northern part, steeplands are the main problem.

Table 2.7 Agricultural problem soils in Thailand by region (ha).

Region	Organic soil	Acid sulfate soil	Saline soil	Shallow soil	Sandy soil	Acid soil	Steeplands
Northern	-	-	-	2,013,418	94,852	2,406,867	9,284,099
North-Eastern	-	-	1,841,101	2,811,352	1,340,582	8,020,730	1,366,684
Central Plain	-	523,338	46,332	706,198	180,285	1,086,914	1,995,107
Eastern	-	202,995	42,105	943,544	59,415	1,210,276	516,691
Southern	42,456	155,290	373,419	463,987	268,040	3,024,412	2,198,536

For the characteristics and management of problem soils in Thailand, The Land Development Department (2015) summarized as follows.

2.4.1 Organic soils

Organic soils are soils that contain at least 20 percent of organic matter in the surface layer and are thicker than 40 cm. The soils are waterlogged and highly acid. If acid sulfate material is present, reclamation becomes more expensive. The major area of organic soils is found in swamps along the coastal area. Soil profile and outlook of organic soils are shown in **figure 2.3a and b**. Organic soils in Thailand occupy a total of 42,456 ha. The main problems for agricultural purposes are such as:

- Flooded for a long time.

(a) (b)

Figure 2.3 Soil profile (a) and outlook of organic soils (b)

- Only slight decomposition of organic material or high wood content.

- Rapid oxidation/ decomposition of organic material after drainage.

- Irreversible shrinkage resulting in adverse water retention characteristics and increased sensitivity to erosion.

- Acute nutrient deficiency after a few years of continuous cropping. Major deficient elements are K, P, N, Ca, Mg, Cu, Zn, B and Mo.

- Al toxicity in some cases where there is an important admixture of inorganic soil materials.

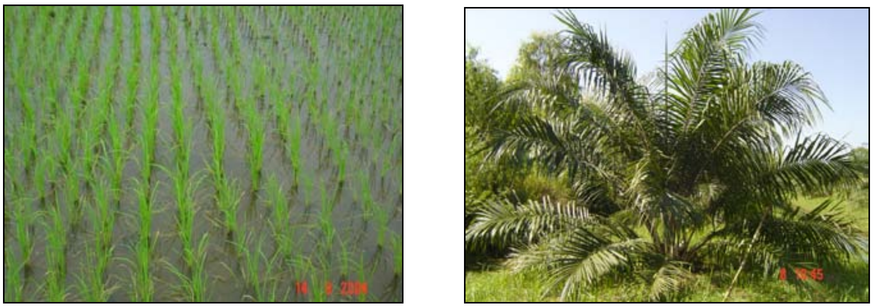
Management of organic soils

- Peat soils should be conserved under natural vegetative cover. However if it is unavoidable, the reclamation of organic soil or peat soil should involve.

- Intelligent design of drainage systems based on accurate soil information. Appropriate for the designed drainage systems; one-meter-deep drains at 20-40 m intervals are satisfactory in most cases.

- Selection of suitable crops such as rice (**Figure 2.4a**), maize, sweet potato, coconut and oil palm (**Figure 2.4b**).

- Applying lime to improve the acid conditions and use of an appropriate fertilizer application program.



(a) (b)

Figure 2.4 Crops cultivation Rice (a) and oil palm (b) in organic soils

2.4.2 Acid sulfate soil

Acid sulfate soil is the common name given to soils and sediments containing iron sulfides, the most common being pyrite. When exposed to air due to drainage or disturbance, these soils produce sulfuric acid, often releasing toxic quantities of iron, aluminum and heavy metals.

Actual acid sulfate soils are strongly acidified by the oxidation of pyrite to sulfuric acid. They have a pH of less than 4, contain oxidized iron sulfides and often contain jarosite (a yellow mottle produced as a by-product of the oxidation process, **figure 2.5**). Toxicity of Acid Sulfate Soils includes phosphorus deficiency; toxicity of aluminium, ferrous iron (Fe_2^+) and hydrogen sulfide. Deficiencies in plant base minerals such as calcium, magnesium and potassium are found. Attack by plant pathogens increases, while the response for nitrogen fixation in soil microbes decreases. The response of sensitive rice variety on acid sulfate soil as shown in **figure 2.6**.

Figure 2.5 Jarosite (a yellow mottle) in acid sulfate soils

Figure 2.6 Effect of acid sulfate soil on sensitive rice variety

For management of acid sulfate soil, lime application is needed to increase soil pH (**Figure 2.7)**. Acid sulfate soils require N and P fertilizer to increase crop yields. Rock phosphate is used as a source of P while ammonium sulfate is used as a source of N. Acidic resistant species such as pineapple, guava and oil palm etc. are to be considered as shown in **figure 2.8**. Land use should be changed from rice to horticulture or orchard plantation. Making bed for plant cultivation should be done (**Figure 2.9**).

Figure 2.7 Management of acid sulfate soil by lime application

Figure 2.8 Management of acid sulfate soil by planting acidic resistant species

Figure 2.9 Management of acid sulfate soil by making bed for plant cultivation

2.4.3 Saline soil

Saline soils are soils that contain considerable amounts of soluble salts. They occur where evapotranspiration greatly exceeds precipitation. The accumulated ions include sodium, potassium, magnesium, calcium, chloride, sulfate, carbonate and bicarbonate. They show high electrical conductivity of saturation extracts from soils (EC_e) of more than 2 dS/m at 25^o C. The processes of salinisation can be separated into 2 processes; primary salinization which involves accumulation of salts through natural processes and secondary salinisation which is caused by human interventions (http://www.fao.org/ag/AGL/agll/prosoil/psintro.htm). Salinity influences plant growth and results in reduced crop yields, and it has been increasingly degrading potential agricultural productivity.

In Thailand salt affected soil covers an area of 2.302 million ha. It can be classified into inland geologic origin in the northeastern region, and coastal salt affected soils originating from seawater. About 1.841 million ha is found in the northeastern region, while other areas of 0.425 million ha and 0.063 million ha are coastal saline soil and other regions, respectively (Office of Soil Survey and Land Use Planning, 2006).

Inland saline soils are distributed in the low lying land of the Northeastern part of Thailand (**Figure 2.10**). About 75 % of this area is under rainfed lowland rice cultivation. The management emphasizes appropriate agronomic practices such as utilization of salt tolerant varieties of KDML 105 with older seedlings, closer spacing of 15x20 cm and an increased number of seedlings (**Figure 2.11a**). Utilization of green manures such as *Sesbania rostrata* are recommended. For severely saline soil, rehabilitation of the area is considered. For revegetation halophytes, namely; *Sporobolus virginicus* (both coarse and smooth type), *Spartina patens* and *Distichlis spicata* are recommended as **figure 2.11b** (Yuvaniyama and Arunin, 1992a), while reforestation was studied in the potential salt source area for salinity control (**Figure 2.11c**).

Figure 2.10 Outlook of inland saline soil

(a) (b) (c)

Figure 2.11 Agronomic management of inland saline soil
(a) Rice cultivation in slightly saline soils
(b) Revegetation halophytes in severely saline soil
(c) Reforestation in the potential salt source area

The coastal saline soils are scattered along the coast of Southern and Eastern regions. They are very saline and most of them are flooded during spring tides only. Outlook of coastal saline soil is shown in **figure 2.12**. The factors limiting plant growth are not only salinity but also potential acidity and degree of development of the soil (Glopper, 1971). Dikes or polders are constructed to prevent high tides from inundating the lands (**Figure 2.13**). The lands are improved by ridging for coconut and other crop plantations (**Figure 2.14**). Rice cultivation is common in these areas. Beside rice cultivation, cash crops such as tomato, cabbage, sweet potato, corn and taro were recommended with organic and chemical amendments and chemical fertilizer application (Arunin, 1992; Im-Erb and Yamclee, 1999).

Figure 2.12 Outlook of coastal saline soil

Figure 2.13 Dikes construction to prevent high tides

Figure 2.14 Agronomic management of coastal saline soil

The central plain saline soils, are generally developed from old marine sediments (Hattori and Takaya, 1987). Outlook of this soil is shown in **figure 2.15**. While **figure 2.16** shows the effect of saline soil on sugarcane growth. The change from rice and sugarcane to higher income cash crops such as cantaloupe (**Figure 2.17a**) and broccoli (**Figure 2.17b**) which are planted with soil amendments; compost, husk ash, bagasse and rice, is recommended.

Figure 2.15 Outlook of central plain saline soil

Figure 2.16 Effect of saline soil on plant growth

(a) (b)

Figure 2.17 Agronomic management of central plain saline soil
(a) For cantaloupe cultivation
(b) For broccoli cultivation

2.4.4 Shallow soils

Shallow soils are soils that have greater than 35 % of rock fragments by volume. They may have a marl layer or layer of base rock shallower than 50 cm that limits plant growth (**Figure 2.18a and b**). These soils are classified as being of low fertility. The capacity of water and nutrient absorption is low. The major land use is rice (65 % of total shallow soil area). It is also used for deciduous forest and other species such as rubber on around 25 % of the total shallow soil area. Thirty percent of gravelly soils are used for deciduous forest while shallow soils with marl layers are used for crop production.

(a) (b)

Figure 2.18 Outlook of shallow soil (a) and soil profile (b)

For management of shallow soils, appropriate selection of plant varieties should be considered as this soil is suitable for fast-growing trees, woodland, pasture, or other crops that provide permanent cover. In cases where soil depth is more than 30 cm, the recommendations to farmers include 1) selection of suitable cultivars such as shallow-rooted plants, drought resistant crops and multiple cropping systems, 2) appropriate cultural practices such as no tillage or optimum tillage, application of organic matter, mulching, chemical fertilizer application and efficient water use. **Figure 2.19** shows green manure as sword bean which used for improvement shallow soil.

Figure 2.19 Green manure for management of shallow soil

2.4.5 Sandy soils

Sandy soils are soils containing sandy material to a depth of more than 100 cm from the surface. Some areas are thicker than 50 cm from the surface with a base of clay shale. The major constraints for agriculture include extremely low nutrient status; low water holding capacity; low cation exchange capacity; low available moisture content and high permeability; low in ECEC, organic matter content and available P and K. Besides poor chemical properties, the physical properties of sandy soil are poor as shown in **figure 2.20**. These result in restricted plant growth. The surface soil is highly erodible.

Figure 2.20 Outlook of sandy texture soils

Management of sandy texture soils can be done by:

a) Soil management: mulching, minimum tillage, soil amendment application, split application complete fertilizer use as well as compost fertilizer for sandy soil improvement.

b) Water management: use of surface irrigation methods particularly sprinkle irrigation (**Figure 2.21a**), and subsurface irrigation by using porous earthenware cylinders to supply moisture at the root zone.

c) Crop management: selection of crop varieties that are tolerant to drought conditions, for example cassava, pineapple, bean, cashew nut tree and forage crops. **Figure 2.21b** shows pineapple cultivation in sandy soil. Fast growing commercial trees are also suggested.

(a) (b)

Figure 2.21 Agronomic management of sandy texture soils
(a) Sprinkle irrigation
(b) Drought tolerant plant such as pineapple

2.4.6 Acid soil

Acid soils are soils that have soil pH lower than 7. The constraints of this soil are both soil chemical and physical properties. For chemical properties, problems are toxicity of aluminum and manganese which can damage root systems; deficiency of phosphorus, potassium magnesium and calcium. Soil erosion may occur in these soils. Furthermore, it was found that plant diseases such as root and foot rot occur frequently. Outlook of acid soil is shown in **figure 2.22**.

Figure 2.22 Outlook of acid soils

Acid soils can be managed in the following ways:

- Application of lime at the rate of lime requirement.

- Utilization of organic fertilizer such as farmyard manure and green manure as shown in **figure 2.23a**.

- Application of chemical fertilizer (N, P and K) to improve soil productivity.

- Mulching with crop residues or legume plants to prevent soil erosion and maintain soil moisture.

- Selection of suitable plant species such as rice, sugarcane, cassava, maize, watermelon, bean, coffee, rubber, oil palm, banana, mango, pineapple, roselle etc. **Figure 2.23b** shows roselle plantation in acid soil.

(a) (b)

Figure 2.23 Agronomic management of acid soils
(a) Utilization of compost plus farmyard manure
(b) Suitable plant species such as roselle

2.4.7 Steeplands

Steep land soils are on slopes steeper than 35 percent (**Figure 2.24a**). Soil erosion is the main problem. After rainfall, the water rushes off the sloping lands, carrying precious topsoil and plant nutrients with it. The other problem is low pH soil. The management of this area includes use of alley cropping and/or grass strips; reforestation and use of cover crops to prevent soil erosion. **Figure 2.24b** shows vetiver grass strips to prevent soil erosion Soil and water conservation should be considered. Application of lime in acid soil conditions to increase soil pH is recommended. Applications of organic fertilizer and chemical fertilizer are recommended to improve soil fertility.

(a) (b)

Figure 2.24 Steepland soils in Thailand
(a) Outlook of steepland soils
(b) Vetiver grass strips prevent soil erosion

Chapter 3

Present status and management of salinity in Thailand

3.1 Definition and appearance of saline soil

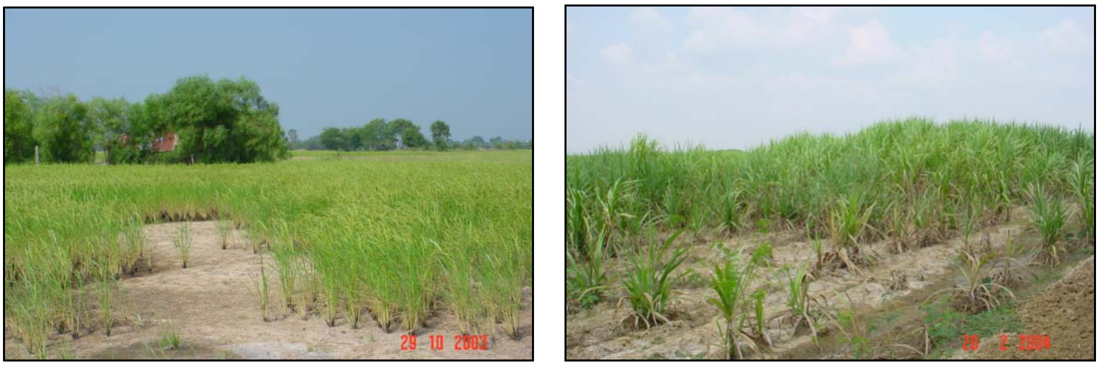
Saline soils are soils containing high levels of soluble salts. This adversely affects plant growth and yield (USSLS, 1954). However, the damage depends on species, varieties, growth stage and environmental factors, so it is difficult to define salinity effects accurately (Ponnamperuma and Banyopadhya, 1980). They show high electrical conductivity of the saturation extract from soil sample (EC_e), exceeding 2 dS m^{-1} at 25^{o}C with SAR (Sodium Adsorption Ratio) lower than 13 (Abrol *et al.*, 1988). Saline soil shows maximum exchangeable sodium percentage (ESP) of less than 15 (SSSA, 1978; USSLS, 1954). Chlorides and sulfates of sodium, calcium and magnesium are usually found. Every year the area of saline soils is increasing and causing major problems for farmers in managing the land (Wongsomsak, 1986). Soil salinity classes generally recognized are given in **table 3.1**.

Table 3.1 Criteria for classifying salinity of soils and crops growth.

Soil Salinity Classes	Conductivity of the Saturation Extract (dS m^{-1})	Salt percentage (%)	Effect on Crop Plants
Non saline	0 - 2	< 0.10	Salinity effects negligible
Slightly saline	2 - 4	0.10 - 0.20	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	0.20 - 0.40	Yields of many crops are restricted
Highly saline	8 - 16	0.40 - 0.80	Only tolerant crops yield satisfactorily
Very highly saline	> 16	> 0.80	Only a few very tolerant crops yield satisfactorily

Source: Adapted from Abrol *et al.* (1988).

In saline soil areas, salt patches will occur in the dry season. Salinity decreases plant growth until plants become chlorotic and die as shown in **figure 3.1a and b**. Indicator plants such as *Azima sarmentosa* (Blume) Benth. & Hook.f. and *Xyris indica* L. are found (**Figure 3.2**).



(a) (b)

Figure 3.1 Rice (a) and sugarcane (b) in saline soil condition

(a) *Azima sarmentosa* (Blume) (b) *Xyris indica* L.

Figure 3.2 Indicator plants were found in saline soil area of Thailand

Salinity adversely influences plant growth, leading to significant reductions in yield and degraded agricultural productivity. The degree of damage depends on species, variety, growth stage and environmental factors. The effects of salinity on plants include impeded water uptake, imbalance of plant nutrients and accumulation of toxic ions (Luttge *et al.*, 1984; Sharma, 1984).

3.2 Present status of salinity

In Thailand, saline soils cover an area of 2.302 million ha (Office of Soil Survey and Land Use Planning, 2006). It can be classified into inland geologic origin in the northeastern region, and coastal salt-affected soils originating from seawater. About 1.841 million ha is found in the northeastern region whereas other areas of 0.425 million ha and 0.063 million ha are either coastal saline soil or other regions, respectively. They can be summarized as following.

3.2.1 Inland saline soil

Inland salt-affected soils are distributed across the low-elevation lands within Thailand's Northeastern region, covering 1.841 million hectares (Office of Soil Survey and Land Use Planning, 2006) or 18 % of agricultural land area of the northeastern part, and resulting from both natural and anthropogenic salinization processes. The appearance of saline soil in northeastern Thailand is shown in **figure 3.3**. Soil series namely; Roi-Et series, Kula Ronghai series and Udon series, generally found in inland saline soil (**Appendix1.1**).

Figure 3.3 Saline soil of Thailand's Northeastern region

The source of salt in this area is halite in the Mahasarakham Formation (**Figure 3.4**), which generally occurs at depths of about 200 m but may be exposed at or near the surface due to the angle of dip of the strata or by development of salt domes (a geologic formation caused by salts and evaporated minerals working their way up through sedimentary rock). The Upper Clastic Member of the Mahasarakham Formation is semi-consolidated clay to claystone/mudstone located within 200 m from the surface. Salt veins previously classified as salt-free have more recently been identified as potential salt sources. The Plio-Pleistocene Formation is composed entirely of clay with montmorillonite as the dominant mineral. This formation occurs within 40 m of the soil surface and is also a source of salt (**Figure 3.5**). The dip of 10-20 degrees in the rock strata locates their exposure at or near the soil surface in different regions across the plateau (Sinanuwong and Takaya, 1974; Wongsomsak, 1986).

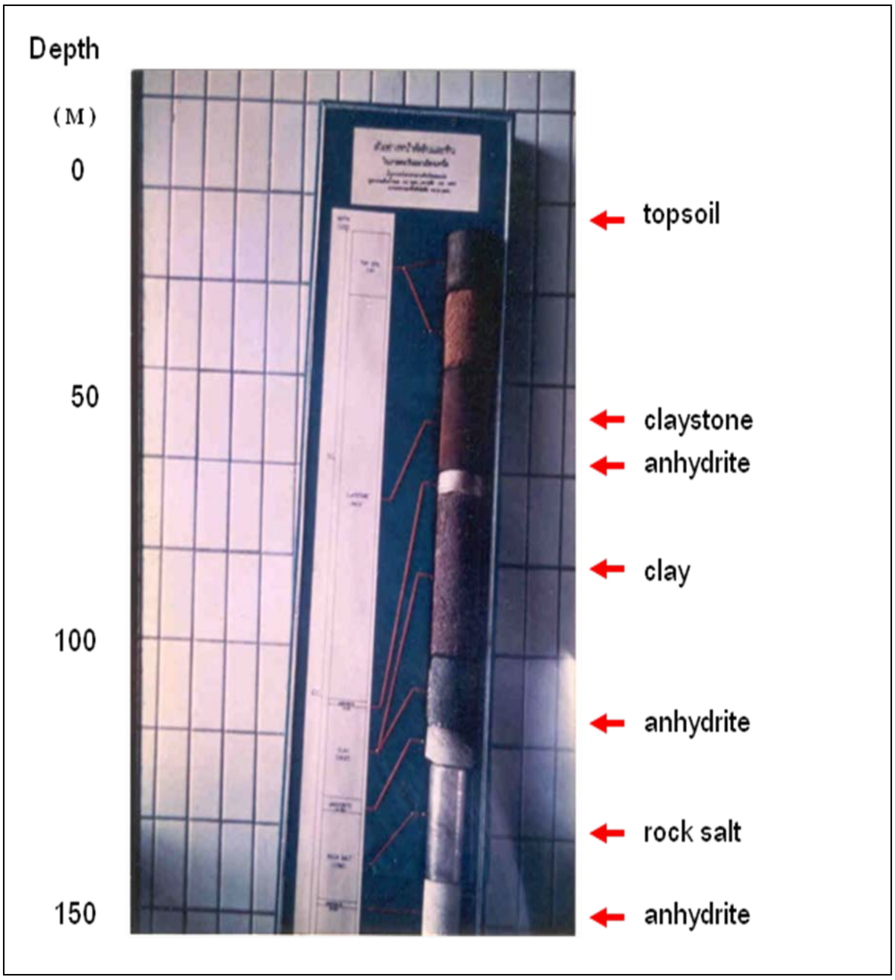


Figure 3.4 A profile of soil and rock salt in the Northeast, Thailand

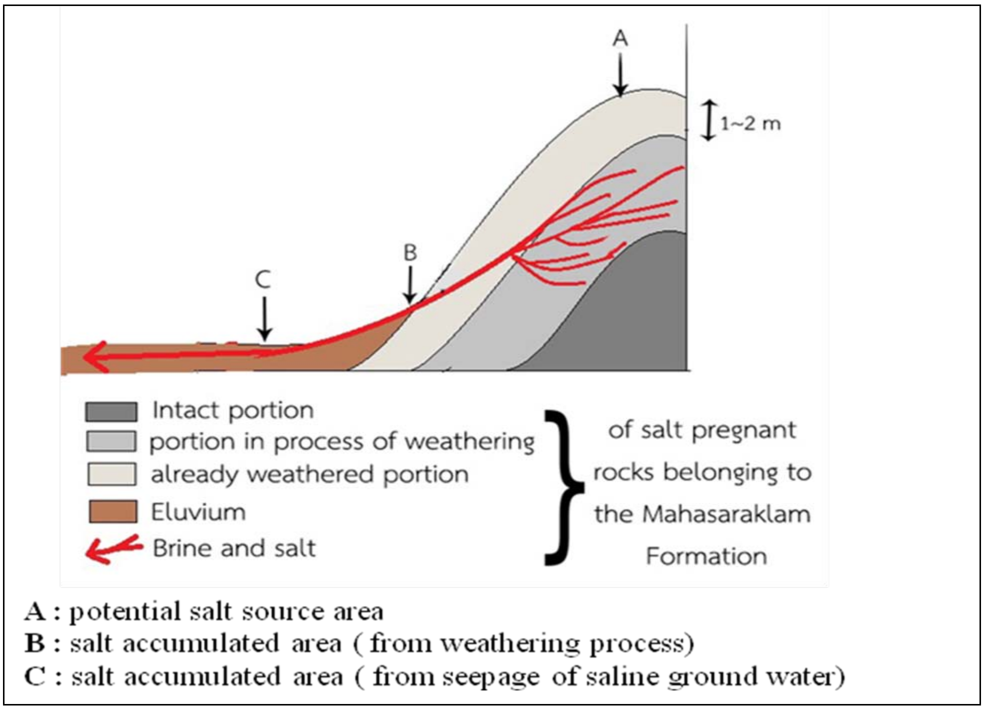


Figure 3.5 Schematic cross-section shows the mechanism of the extraction of salt from the salt formation (Sinanuwong and Takaya, 1974).

Besides the inherent salt-bearing nature of the parent materials, human interventions also contribute to anthropogenic salinization processes as followings.

- Deforestation

The forest cover in the northeast has declined due to deforestation. Land use was changed to processed cash crops particularly cassava and kenaf. Deforestation caused saline seepage and consequently salinization over a wide area. Clearing native vegetation, cropping and changing land use in the recharged zones resulted in a rise of saline groundwater level. This saline groundwater emerged in the discharge zones and the salt easily accumulated at the soil surface (**Figure 3.6**). Finally, the area became unused; plants could not grow except for salt tolerant weeds (Arunin, 1989). While Peck *et al*. (1987) summarized that deforestation has increased the rate of salt release from the salt-laden strata. Changes in hydrologic conditions following land clearing can result in rising water tables that are capable of dissolving residual salts and carrying them through seepage to slope and bottomlands. Abrol *et al.* (1998) reported that saline seeps, common in North America, Australia and other countries, are the result of excessive leaching that results from reduced evapotranspiration after a change in land use from a natural forest vegetation to a cereal grain crop or a shift in cropping pattern such as the introduction of a fallow season in a grain farming system. The percolating water passing through saline sediments is intercepted by impermeable horizontal layers and conducted laterally to landscape depressions causing extensive soil salinization (Doering and Sandoval, 1976).

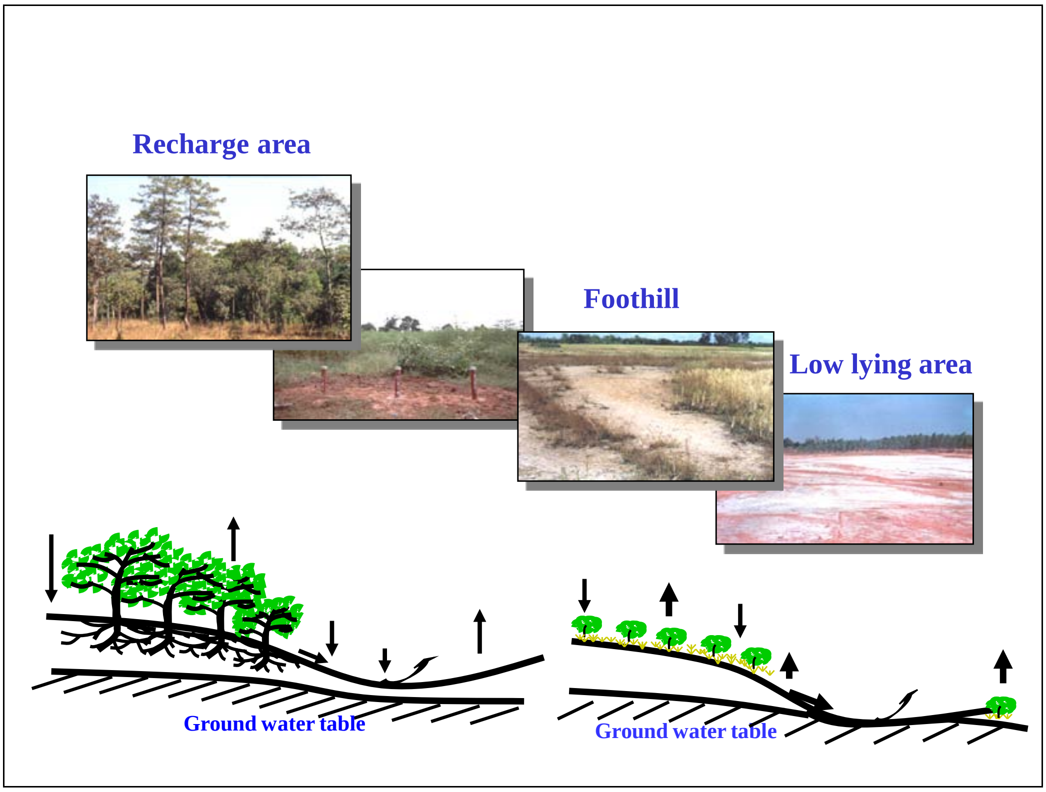


Figure 3.6 Change in hydrologic conditions after land clearing

- Reservoir construction

Reservoir construction in potential salt sources that have shallow saline groundwater causes salinization. Salinity problems will exist in the vicinity of these reservoirs and spread out over an ever wider area from the reservoirs as shown in **figure 3.7**. In addition, water in the reservoirs tends to become saline water a few years after construction (Arunin *et al*., 1987c). So the reservoir construction on the saline or shallow saline groundwater area tended to yield saline water in the reservoirs.

Figure 3.7 Reservoir construction in potential salt source

- Inappropriate irrigation practices

In the case of irrigation, utilization of low quality irrigation water with inefficient or inadequate drainage causes rapid man-made salinization (**figure 3.8**). The salts are applied to soil with the water and accumulate in the soil surface as water evaporates or is used by the crops and the soil water eventually contains a higher concentration of salts than the applied water. The extent of the salts accumulated in the soil will depend upon the irrigation water quality, irrigation management and drainage system. If salt concentrations become excessive, this results in yield losses (Ayers and Westcot, 1985). Abrol *et al*. (1988) discuss the use of saline groundwater: when groundwater is the only source available for irrigation, high salinity of the irrigation water can cause a build up of salts in the root zone, particularly if the internal drainage of the soils is restricted and leaching, either due to rainfall or to applied irrigation, is inadequate.

Figure 3.8 The extent of the salts accumulated at soil surface

- Salt-making

The process of salt-making includes pumping of saline groundwater (50-60 dS m^{-1}) from a depth of about 20 m or dissolved brine from a rock salt bed and flooding the soil surface. Saline water will evaporate, leaving the salt behind (**Figure 3.9**). This causes adjacent and downstream lands to become saline (Arunin, 1989). Salt-making becomes a conflicting use of land and water resources and, in addition, environmental problems occur. Degradation of agricultural land as well as deforestation and land subsidence has been observed.

Figure 3.9 Traditional salt-making in northeast Thailand.

Sukchan (2004) surveyed and mapped saline soil management in the Chi River basin (part 3), and the results showed that saline soil did not show a relationship with soil texture. This means that saline soil can be found in all types of soil texture (light and heavy texture).

The saline soils of the northeast are concentrated in the Sakon Nakhon and Korat basins. Soil salinity maps at a scale of 1:250,000 classify the problem areas as slightly, moderately, heavily and potentially salt-affected land (Arunin, 1984) as shown in **figure 3.10**.

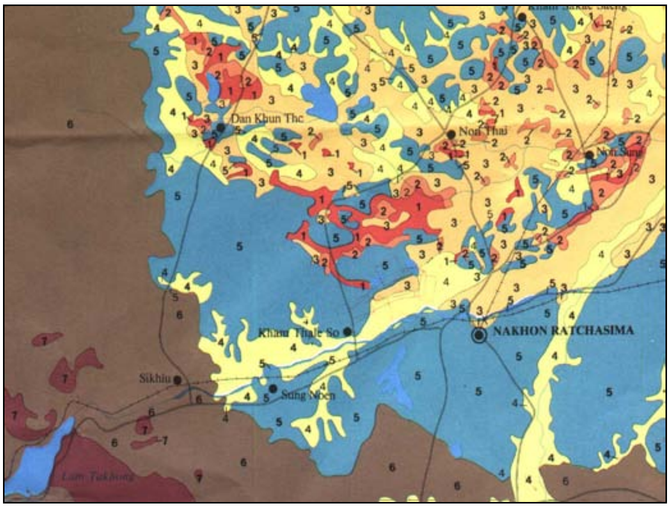


Figure 3.10 Soil salinity maps of Nakhon Ratchasima province at a scale of 1:250,000

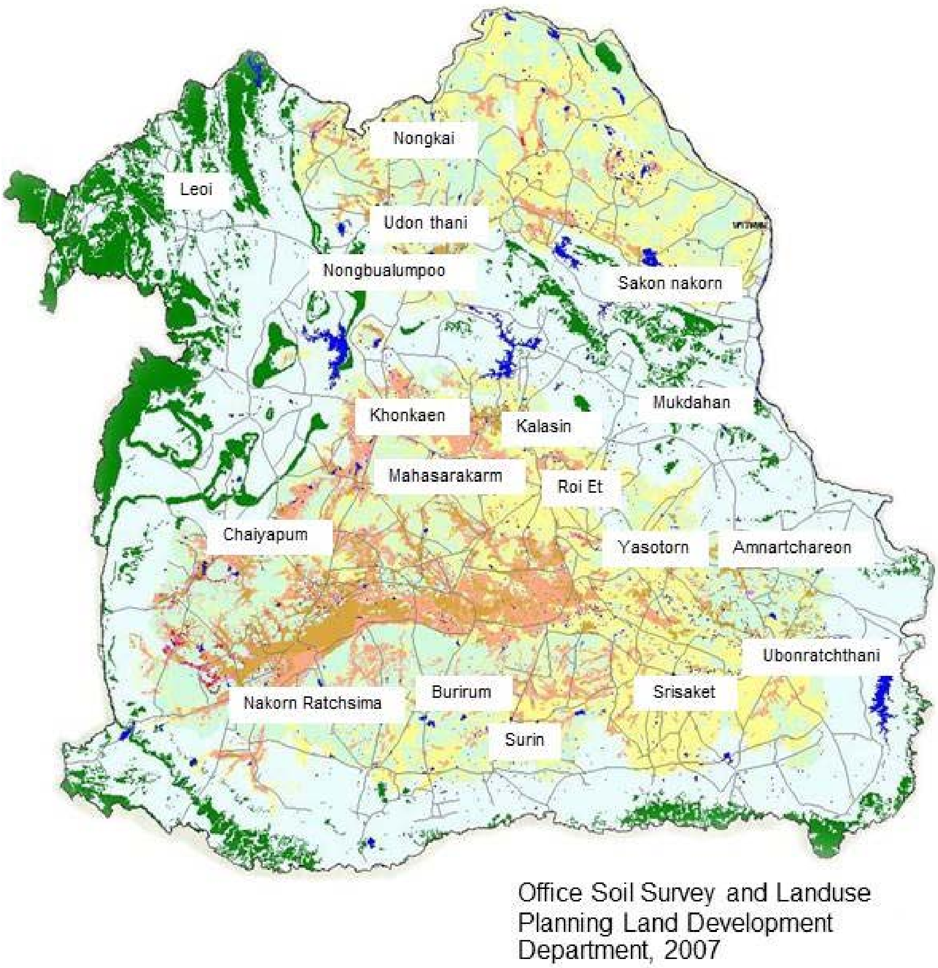
An updated salinity map at 1:100,000 scale has also been published. In this map, saline soils are classified by the presence of salt patches on the soil surface, i.e. more than 50% of salt patches is severely affected (53,160 ha), between 10-50 % of salt patches found is moderately affected (613,815 ha) and less than 10 % of salt patches are classified as slightly affected (1,174,126 ha), potential salt source areas or elevated areas where salt is found in deeper layers (3,134,304 ha). The appearances of salinity classified by the presence of salt patches are shown in **figure 3.11**. The information from salinity maps is used for management planning to mitigate the salinity problems of Thailand. This map was revised and classified by Sukchan (2007) as shown in **figure 3.12**. However, secondary salinization presents additional complexity for mapping saline soils due to rapid salt migration. The distribution of saline soil areas in each province is shown in **table 3.2**.

(a) Slightly salt-affected soil

(a) Moderately salt-affected soil

(c) Severely salt-affected soil

Figure 3.11 Level of salinity classified by the presence of salt patches



- Severely saline soil: salt patches on the soil surface more than 50% (16,643 ha)
- Highly saline soil: salt patches on the soil surface 10-50% (36,517 ha)
- Moderately saline soil: salt patches on the soil surface 1-10% (0.614 million ha)
- Slightly saline soil: salt patches on the soil surface less than 1% underlaid by rock salt; with saline ground water (1.178 million ha)
- Slightly saline soil: salt patches on the soil surface less than 1% underlaid by rock salt; with non saline ground water (3.15 million ha)
- Recharge area (potential salt source area)
- Non salt-affected area
- Salt making area
- Mountainous area
- Water area

Figure 3.12 Distribution of saline soils in Northern part of Thailand by Sukchan (2007)

Table 3.2 The distribution of saline soil areas in each province in Northeastern part of Thailand (ha).

Provinces	**Salt patches > 50 %**	**Salt patches 10-50 %**	**Salt patches 1-10 %**
NaKhon Ratchasima	11,196	18,540	23,5782
Chaiyphom	2,539	5,127	32,608
Buri Ram	17	226	18,182
Surin	19	89	22,375
Khon Kaen	398	4,234	42,451
Maha Sarakham	98	2,003	57,055
Kalasin	55	89	25,230
Udon Thani	740	1,674	45,031
Nong Khai	158	332	3,008
SaKon NaKhon	1,106	215	8,876
Nong Bua Lam Phu	-	-	-
Ubon Ratchathani	111	1,164	35,817
Si Sa Ket	22	37	4,855
Yasothon	-	13	11,332
Roi Et	141	2,511	57,232
Amnat Charoen	-	239	10,707
Nakhon Phanom	44	25	3,274
Mukdahan	-	-	-
Loei	-	-	-
Total	**16,643**	**36,517**	**613,815**

In general, salt-affected soils in the northeast are high in sodium and chloride content, sandy and low in fertility, with approximately 75 % under rainfed lowland rice cultivation (Arunin, 1984).

3.2.2 Coastal saline soils

Coastal salt-affected soils are found scattered along the coast of the Southern and Eastern regions, covering an area of 0.425 million hectares (Office of Soil Survey and Land Use Planning, 2006). These areas are subject to tidal influences and brackish or sea water intrusion. These soils are very young heavy clay or silty clays with little profile development. They are very saline and most of them are flooded during spring tides only. Factors limiting plant growth include not only salinity but also potential acidity and degree of maturity of the soil (Glopper, 1971). The characteristics of coastal saline soils is shown in **figure 3.13**. Soil series namely; Samut Prakan series, Bang Pakong series and Tha Chin series, generally found in coastal saline soil (**Appendix1.2**).

Figure 3.13 Characteristics of Coastal saline soils

The rapid increase in numbers of shrimp ponds emerged as an important problem in these areas because shrimp ponds displaced mangrove forests and agricultural lands. A study of the impacts of shrimp farming on coastal ecosystems was therefore prioritized; and it examined the impacts of nutrients and sediment discharge on the performance of mangrove, and the response of mangrove to added nutrients. The study also examined the capacity of mangrove ecosystems to degrade pollutants from shrimp farming. During 1996-1998, the Land Development Department studied lateral seepage of salinity from shrimp ponds in a brackish coastal area (Songkhla Province) and fresh water alluvial deposits (Suphanburi Province). The results showed high salinity levels adjacent to shrimp ponds and decreased from 36 to 3.9 dS m^{-1} in Songkhla Province, where in Suphanburi

Province salinity dropped from 8 to 1.0 dS m^{-1} at the distance up to 800 m as shown in **table 3.3** (Im-Erb *et al*., 2001).

Table 3.3 Salinity from ponds and piezometers (dS m^{-1}).

Sites	**Distance from the culture pond (m)**								
	0	**10**	**20**	**50**	**100**	**200**	**400**	**600**	**800**
Songkhla	36.0	no data	15	no data	no data	11.0	14.0	3.3	3.9
Suphunburi	8.0	4.8	5.5	5.1	4.4	2.8	2.1	no data	1.0

Source: Im-Erb *et al*. (2001)

3.2.3 Central Plain saline soil

In the Central Plain saline soils have generally developed on marine sediments (Hattori and Takaya, 1989). This area was normally flooded by sea water in the past. Unsuitable land use such as utilization of saline groundwater for irrigation; unsuitable irrigation and excavating surface soil for sale, have created a wider distribution of salinity problems. Central Plain saline soils are found scattered in Nakhon Pathom, Suphan Buri, Kanchanaburi, Ang Thong, Sing Buri and Chai Nat provinces. They cover an area of 46,332 ha. Rice and sugarcane cultivation are common, although yields are generally low (**Figure 3.14**). The soil series that has salinity problem such as Kamphaeng Saen Series (**Appendix1.3**).

Figure 3.14 Characteristics of Central Plain saline soils

3.3 Present management of salt affected lands

During the past 20 years, the Soil Salinity Research Section of the Land Development Department has carried out numerous studies related particularly to the agronomic aspect of crops tolerant to salinity, chemical and physical properties of saline soils, landscape salinity and salt water management, salt tolerant trees, halophyte and etc., with the cooperation of IRRI, ACAIR, JICA, and USAID (Arunin, 1992).

According to the 5th and 6th Thai National Economic and Social Development (NESDB) Plans (1982-1991), the management strategies emphasized low input technology for increasing crop yield in slight and moderate salt affected lands. An agronomic program had been developed and disseminated to the farmers' fields through demonstration and training. However, the area of saline soil is still increasing in the northeast and the central plain of Thailand, caused by mismanagement (Arunin, 1992; Yuvaniyama and Arunin, 1989).

In the 7th NESDB Plan (1992-1996), the prevention of further salinization and the reclamation and the utilization of severely saline soil are planned. Prevention can be either by vegetative or engineering measures in order to prevent salinization in the potential salt source area and on some severe saline soils through reforestation and curbing illegal salt making. However, reclamation costs have to be determined under various socio– economic environments, as well as their impacts (Yuvaniyama *et al*., 1996).

Management and remediation of salt-affected soils depends upon the degree of salinity and specific salinization processes through agronomic management, biological/chemical management and engineering management approaches. The main approaches are described below.

3.3.1 Agronomic management

The appropriate agronomic management depends upon the degree of salinity and the prevalent local salinization processes. In general, present recommended strategies include leaching, land leveling, surface mulching, application of organic amendments, deep plowing, utilization of salt tolerant varieties and the prevention of further distribution of saline soil (Pongwichian *et al*, 2013; Arunin and Pongwichian, 2015). The main approaches are described below.

a) Agronomic management of slightly and moderately saline inland soil

Arunin (1984) reported that slightly to moderately salt-affected soils are typically used for rice cultivation, however, rice yields are low. The appearance of rice in saline soil is shown in **figure 3.15**. Arunin (1992) recommends appropriate agronomic management for increasing rice yields; these include selection of KDML 105, a highly salt-tolerant rice variety, transplanting of seedlings at thirty to thirty-five days old, closer spacing of 15x20 cm, with an increased number of seedlings (6-8 seedlings/hill) and application of organic soil amendments such as green manure, farmyard manure and compost to increase soil fertility and improve physical properties of soil. Due to the high price of chemical fertilizers and their environmental impact, and the shortage of organic materials for producing compost, the use of green manures has been put as a high priority (**Figure 3.16**). Numerous studies indicate that a leguminous plant, namely *Sesbania rostrata,* shows high potential as a green manure crop in saline soils for rainfed lowland rice systems in Thailand (Arunin *et al.*, 1987a; 1988; 1992a; 1994; 1995a; Anuluxtipun *et al.*, 1992; Pongwichian *et al.*, 1997; 1998; 2006 and Thamphang, 1992). Use of organic amendments in combination with reshaping the paddy field was another effective method to increase rice yield in salt affected land. Furthermore, land leveling with planting salt tolerant trees e.g. *Acacia ampliceps* on the ridge has successfully remediated the moderately salt affected soils (Arunin and Pongwichian, 2015).

Figure 3.15 Appearance of rice in saline soil

Figure 3.16 Appropriate agronomic management for increasing rice yields

Salt tolerant crops such as asparagus, tomato, garlic, chives, cantaloupe, broccoli, Chinese kale can be grown combined with agronomic managements which include the application of organic matter such as manure, compost, green manure, rice husk, mulching to retain soil moisture and prevention of the accumulation of salt on the surface with drip irrigation systems. However, more salt tolerances varieties are shown in **appendix2** and suitable placement of seed in saline soil are shown in **appendix3**.

b) Agronomic management of inland severely saline soil

Inland severely saline soils are typically considered as waste land, however they can be rehabilitated. Utilization of salt tolerant species and varieties is recommended. Yuvaniyama and Arunin (1992a and b) reported that the exotic halophytes namely *Sporobolus virginicus* [both coarse type (Dixie grass) and smooth type (Smyrna grass)], *Spartina patens* and *Distichlis spicata* could survive in severely salt-affected soils of 42 dS m^{-1}. Dixie grass showed high performance for inland saline soil in northeast Thailand (**Figure 3.17**). This species has been distributed to farmers by an implementation project that was conducted by the provincial Land Development Station. The mechanisms of their tolerant ability include osmotic adjustment in plant, exclusion of salt by roots, water storage in tissues, salt avoidance, ion accumulation and sequestration or excretion of salt via glands in plant leaves or stem (Flowers, 1975; Gallegher, 1979; 1985). For example, Dixie grass excretes salt via glands in plant leaves (**Figure 3.18**). For salt-tolerant trees, *Acacia ampliceps, Casuarina glauca* and *Melaleuca acaciodes* grew successfully in the severely salt-affected soils (Dissatapom *et al*., 1992), while some native species namely *Azadirachta indica, Cassia siamea, Tamarindus indica* and *Pithecellobium dulce* could also tolerate high salinity levels (**Appendix4**).

Figure 3.17 *Sporobolus virginicus* (Dixie grass)

Figure 3.18 Salt gland of *Sporobolus virginicus* (Dixie grass)

c) Agronomic management of coastal saline soils

The management of coastal salt-affected soils needs to cope with the specific characteristics of local soil, crop and water regimes. For rice cultivation, salt-tolerant rice varieties such as Lebmue Naang 111, RD 19, RD 27, KDML 105 and Hom Nai Pran were recommended. Economic crops such as tomato, cabbage, sweet potato, corns, cantaloupe and taro were recommended with organic amendments and chemical fertilizer application (Arunin, 1992). For example, with cantaloupe cultivation, Prosayakul and Tanprapart

(1998) reported that appropriate irrigation with mulching gave higher yield. In addition, utilization of farmyard manure plus chemical fertilizer was also recommended, while Im-Erb and Yamclee (1999) reported that removal of soluble and exchangeable sodium from the root zone was necessary. However, farmers have also used indigenous technologies to reclaim their lands, often using soil ridging for cultivation of coconuts and other crops. The width of the ridges is usually 6-7 metres (**Figure 3.19a and b**).

Plantation of salt tolerant crops for land rehabilitation was recommended. Im-Erb *et al*. (1994) reported that *Spartina patens* showed a higher survival percentage than *Panicum repens, Sporobolus virginicus* (coarse) and *S. virginicus* (smooth). It could be concluded that *S. patens* was suitable for environmental rehabilitation of coastal salt-affected soils, especially areas polluted by shrimp farm effluents as well as soil improvement. While Pongwichian *et al*. (2014a) reported that Dixie grass (*Sporobolus virginicus* coarse type) showed the highest survival rate and Seabrook grass had the highest growth, highest fresh and dry weights, and the best nutrient accumulation, especially of nitrogen and sodium in Petchaburi province. This resulted in a greater reduction in electrical conductivity and sodium in the soil than from planting the other grasses or allowing grasses to grow naturally.

(a) Jujube *(Zizyphus mauritiana* Lam*)* (b) Vegetables

Figure 3.19 Soil ridging for cultivation of cash crops.

d) Agronomic management of central plain saline soils

Numerous studies have indicated that appropriate agronomic management such as selection of salt-tolerant varieties, mulching, application of organic amendments (green manure, compost, farmyard manure) and drip irrigation can increase crop yields. Changing rice and sugarcane to higher income cash crops is recommended (**Figure 3.20**). Successful production of asparagus and cantaloupe using soil amendments (compost, husk ash, bagasse and rice husk) was reported by Arunin *et al.* (1995b), while Hongnoi *et al*. (1999) reported that the use of drip irrigation for asparagus resulted in increased yields in saline soils. Pongwichian *et al.* (2001) reported that broccoli yields under saline conditions could be increased by planting on sloping mounds, mulching with plastic sheeting and transplanting seedlings at 25 days. However, socio-economic considerations such as farmer acceptance and market access must also be taken into account in making such recommendations. Pongwichian *et al.* (2007) reported the effects of soil amendments on yield of field crops such as sugarcane grown on saline, infertile soils (EC_e 8.81 dS m^{-1}). It was found that use of farmyard manure was the superior treatment, leading to higher yields than those obtained from treatments of compost and *S. rostrata* green manure. Use of farmyard manure also tended to show higher cane juice quality. The results showed that soil amendments resulted in higher organic matter content, available phosphorus and potassium while soil electrical conductivity (EC_e) tended to decrease. Application of organic fertilizer plus chemical fertilizer was also recommended in central plain saline soils. Pongwichian *et al*. (2014b) reported that it resulted in increased growth of physic nut but not at significantly different levels to the control treatment. Application of organic fertilizer plus chemical fertilizer resulted in a higher yield than the application of chemical fertilizer only and than the control, but not to a significant degree.

(a) Cantaloupe

(b) Asparagus

Figure 3.20 Changing rice and sugarcane to higher income cash crops

3.3.2 Biological/chemical management

a) Biological management

Besides agronomic management, biological processes can improve and reclaim slightly and moderately saline soil. Some groups of microorganism can fix plant nutrients and then change them to forms available for crop growth. These salt tolerant microorganisms can live in roots in saline soil, especially in rice root systems. They are classified as aerobic halophilic bacteria (Tilak *et al*., 2005) namely *Halomonas* sp., *Flavobacterium* sp., *Halobacillus* sp, *Bacillus pumilus* and *Bacillus firmus*. The other free living bacteria that are found in root systems include *Pantora*, *Citrobacter*, *Microbacterium* and *Stenotrophomonas***.**

The understanding of adaptation of the Halo bacteria to life at high salt concentration was studied by Oren (2002). Das *et al*. (2008) summarized that the diversity and salt tolerance of the *Bacillus thuringiensis* isolates suggests that they may be able to control different arthropod pests in saline rice fields. The isolation and characterization of endophytic bacteria from the holophyte *Prosopis strombulifera* that grows in high salinity and the evaluation of the bacterial mechanisms related to plant growth was studied by Sgroy *et al*. (2009). Meanwhile Yamagnchi *et al*. (2011) reported that a moderately helophilic bacterium, *Kocuria varians* could produce active α - amylase [*K. varians* α - amylase (KVA)]. However, the studies on helophilic bacteria in Thailand are limited.

b) Biological management of potential salt source area

Deforestation in the northeastern part of Thailand has exacerbated the salinity problem. A rising water table has resulted in increased available water for aquifer recharge, whilst local groundwater flowing from cleared uplands to saline lowlands increases salinity along the flow path (Peck *et al.*, 1987). It is now recognized that reforestation in the potential salt source area has effectively reduced total discharge to the lowlands, thus lowering the water table. This approach was supported by the findings of Arunin (1989; 1992). Therefore, biological management is used in potential salt source areas by reforestation for salinity control. *Eucalyptus* is a fast growing tree used for reforestation project (**Figure 3.21**).

Figure 3.21 *Eucalyptus*, fast growing tree used for reforestation project

Reforestation is a readily-applied practical measure requiring low inputs, and is well accepted by farmers. In a reforestation project conducted by the Soil Salinity Research Section, Land Development Department in Nakhon Ratchasima Province, northeastern Thailand, groundwater levels were lowered in the recharge area from 4.81 to 5.87 m below the soil surface. In the discharge area, the groundwater level was lowered from 0.48 to 1.04 m. The salinity of groundwater measured through many sets of piezometers at different depths corresponded to those measured by the Electromagnetic terrain conductivity meter (EM) in the recharge and discharge areas ranged from 0.6-1.3 dS m^{-1} and 5.80-7.35 dS m^{-1}, respectively as shown in **appendix5** (Arunin *et al.*, 1999). The lower groundwater levels are attributed to the high consumptive water use of trees, which is similar to other findings that annual water use of Eucalyptus plantations amounted to 1,230 and 270 mm $year^{-1}$ in moderately and severely saline soils, respectively (Tandatemiya, 1996). Furthermore, planting salt tolerant grasses between trees decreased salt accumulation in the root zone of the trees (Dissataporn *et al*., 1992), while Im-erb and Yamclee (1996) reported that reforestation tended to lower groundwater level and EC in both recharge and discharge areas. *Azadirachta indica* and *Eucalyptus camaldulensis* could survive and thrive in the recharge area while *Acacia ampliceps* showed good performance in discharge areas. These were confirmed by a report of Pongwichian *et al*. (2004). Although the research results showed the high potential of growing trees in the recharge upland to lower the groundwater level for salinity control, socio-economically, reforestation may be not feasible unless the government provides subsidies and incentives for small farmers, the majority of whom lack land tenure. Nevertheless, the majority of farmers in this area showed good acceptance of the reforestation project.

c) Chemical management

Saline soil has poor physical properties and an excess of Na, so it is necessary to remove Na from the soil and so improve physical properties. The most common amendment is gypsum. In saline conditions (high Na concentration), dispersion of clay particles is found and this restrains plant growth. Soil physical properties should be improved. Numerous studies showed that gypsum is a suitable amendment for the solution of this problem. Gypsum application resulted in a decrease in dispersion ratio, while, hydraulic conductivity, water infiltration, aggregate satiability increased (Sharma, 1971; Sharma *et al*., 1982).

The study of gypsum effects in saline soil in Thailand is limited. However, there are some research results and reports, e.g. Prosayakul *et al*. (1993) investigated the effect of leaching and amendments on properties of coastal saline soil. It found that application of gypsum and then leaching by water resulted in a significant decrease in exchangeable sodium percentage (ESP). The other study on effects of gypsum, rice husk and *Acadia* leaf on rice yield and soil properties in saline sodic soil was conducted by Buakhao (2012). It was found that application of gypsum at rates of 3.125 t ha^{-1} decreased sodium adsorption ratio (SAR) and tended to give higher rice yield of 2.46 t ha^{-1} when compared to other amendments. Sirival (2011) reported that gypsum is used in agriculture as a soil conditioner, especially in acid soil and saline soil. Gypsum application results in a reduction in acidity, salinity and soil compaction, and finally it is beneficial for plant growth.

Generally saline soils in northeast Thailand are of low fertility and poor physical properties (high bulk density, low permeability), so soil improvement by using chemical fertilizer is needed. For rice cultivation, split application of chemical fertilizer was suggested by Arunin *et al*. (1981). This method reduced nutrient loss from leaching, and it could increase efficient use of nutrients. However, the type of chemical fertilizer should be considered carefully because it may increase salt concentration in the soil solution. Another other study showed that application of only N fertilizer gave higher rice yield than only P and K. It also found that application of N plus P or K gave higher yields than using P plus K. This was reported by Arunin *et al*. (1987b). Generally, rice yield increased with increasing rate of N, P and K fertilizer. However, cost should be considered due to chemical fertilizer being expensive.

Data from soil classification showed that saline soils in northeast Thailand are of low fertility and have poor physical properties due to it having coarse texture with high infiltration rates and hydraulic conductivity. The measure for reduction of these two properties was studied by using Na Montmorillonitic Phimai Clay (2:1 clay type) as a conditioner in sandy paddy saline soil. The experiment was carried out in a farmer's field where the soil was an infertile sandy loam. Clay saturated with Na and Phimai clay at the rates of 0.05, 0.1, 0.5, 1.0 and 2.0 % of total soil weight of 20 cm depth were applied for testing. The objective was to assess change in the physical properties of rainfed lowland sandy soil with clay as a conditioner. After incorporation, the rice yield tended to increase with increasing rate of Na-clay and content while infiltration rate, hydraulic conductivity and bulk density tended to decrease. Clay application could be partly attributed to the increasing nutrient contribute for rice. The rice yield was negatively correlated with infiltration rate, hydraulic conductivity and bulk density. However, they did not show significant differences between Na-clay and non-Na clay at the same rate (Pongwichian and Arunin, 1993b). Although rice yield tended to increase, this method was not suitable for farmers because the capital cost was very high. It was not considered worthwhile, as it was difficult for farmers to bring clay from another place to incorporate into their lands.

3.3.3 Engineering management

Engineering methods through leaching and drainage are effective methods in the reclamation of severely saline soils, but this technique requires high investment. The system is generally only feasible as a large-scale government initiative, as the farmers or land owners cannot do it by themselves. The Land Development Department studied the effect of the polder system on the reclamation of severely saline soils in Khon Kaen province (**Figure 3.22a and b**). The polder system comprises canals and perimeter embankments to control levels of ground and surface water and subsequently control salinity hazard in the system by manipulating groundwater levels. After that the area in the polder system can be used to cultivate cash crops such as asparagus, tomato, cantaloupe or Chinese kale (Dissataporn *et al*., 1997).

(a) Year 1993 (b) Year 2002

Figure 3.22 Appearance of severely saline soil after construction polder system at Khon Kaen province, in the year 1993 (a) and 2002 (b)

The other engineering methods are open (**Figure 3.23**) and sub-surface drainage (**Figure 3.24**) which can be effective in leaching and drainage of saline groundwater in severely saline soils. A study on drainage systems in Mahasarakham Province in northeastern Thailand showed that sub-surface drainage decreased soil salinity in the soil profile more than open drains. Moreover, levels of Na^+ in open drains was reduced by the use of polymaleic anhydride (PMA) application although its effect lasted only 30 days (Hirunwatsiri *et al*., 2003).

Figure 3.23 Open drainage system at Khon Kaen province, Thailand

Figure 3.24 Sub-surface drainage system at Khon Kaen province, Thailand

Furthermore, engineering methods such as dikes (**Figure 3.25**) can be constructed to prevent high tides from inundating the lands, with sluice gates to regulate brine and fresh water flows (Arunin *et al.*, 1995b).

Figure 3.25 Sluice gates for regulating brine and fresh water flows

These integrated methods (agronomic, biological and engineering management) subsequently guided extension in farmer fields in the provinces of Nakhon Ratchasima and Khon Kaen, resulting in increased rice yields and reduced soil electrical conductivity in the topsoil.

Many studies in managing salinity problems and successfully coping with it are recognized. However, more integrated research of various fields is needed for remediation as many problems still remain unsolved. These are listed by Arunin and Pongwichian (2015) as follows.

- Integrated salinity management coupling up with community participatory network.

- New technologies for irrigation and cropping management, for example, reuse of desalinized water, moisture deficit irrigation regulation to maintain crop yield, and the application of suitable crop water salinity models.

- The impact of shrimp farming on the coastal ecosystem.

- Salinity and biodiversity; halophytic bacteria, ecological system of reclaimed salt affected soils and soil communities e.g. study of salt tolerant earthworms.

- Effect of climate change on salinity problem and management.

- Accurate salt affected soil mapping techniques through application and interpretation of various techniques such as Airborne hyperspectral technology, Advanced spaceborne thermal emission and reflection (ASTER), Normalized Difference Vegetation Index (NDVI) with utilization of Electromagnetic Conductivity Terrain Meter for classification of recharge and discharge areas.

Chapter 4

Empirical study of agronomic management of saline soil in agricultural land

As data from the three managements mentioned above, it can be summarized that agronomic management showed the best practice and is suitable for the farmers of Thailand. So the purposes of this dissertation are to find out site-specific methods of using appropriate agronomic management with different salt tolerant species in saline soils of Thailand and to establish the soil productivity using appropriate agronomic management with different salt tolerant species in the saline soils of Thailand. The originality of this research is to figure out the best agronomic management (site-specific) in all types of saline soils (lowlands) in Thailand.

The dissertation on **"Agronomic Management of Saline Soil in Agricultural Lands of Thailand"** has been studied and compiled from the year 1993-2015. The study areas cover all types of saline soil in Thailand. For inland saline soil, the experiments were conducted in the northeastern part of Thailand while the experimentation on coastal saline soil was carried out in Petchaburi province. For the central plain saline soil, the experiments were conducted in the central part of Thailand. All areas are lowlands. For plant types, salt-tolerant species of paddy, *Sesbania* spp., halophytes (4 species), broccoli, sugarcane and physic nut were tested in the farmers' fields. Measured parameters, data of plant growths and yields were collected. Soil samples following the experiments were analyzed for soil properties such as pH, EC_e, OM, available nutrients (N, P, K) and soluble Na. Data presented in this dissertation are the mean values of the replicates for each combination of the treatments. Statistical analyses were performed using IRRISTAT and STATISTIX (version 8.0) to determine the effect of different treatments. One way and two way ANOVA (analysis of variance) were used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) and LSD (Least Significant Difference) were used. It can be concluded that in inland saline soil, if used as a green manure, *Sesbania rostrata* has high potential to mitigate soil salinity in agricultural lands. For coastal saline soil, environmental rehabilitation by salt tolerant halophytic grasses such as Seabrook grass, is recommended in severely saline soils. For central plain saline soil, cash crops such as broccoli, sugarcane and physic nuts grow well with organic and chemical fertilizer in the slightly and moderately saline soil. These studies are described in full as follows.

4.1 Utilization of green manure on inland saline soil

Slightly to moderately salt-affected soils are typically used for rice cultivation due to rice is moderately salt tolerant plant (Alphen, 1983). Horie *et al*. (2012) summarized that rice (*Oryza sativa*) plants are classified as glycophytes. The mechanisms of salt tolerance include prevention water loss due to the increased osmotic pressure, development of Na^+ toxicity on essential cellular metabolisms, and the movement of ions via the apoplastic pathway.

Arunin (1992) recommends appropriate agronomic management for increasing rice yields as mentioned before. Due to the increase in the price of chemical fertilizers and their environmental effects, the use of organic fertilizer has become both feasible and extensive. Organic manure includes compost, farm yard manure and green manure as N-sources and more attention has been given to green manure in particular. Residual effects on salinity and acidity are found after extended use of fertilizer. Some chemical fertilizer, especially N fertilizer, is inefficient and has high N loss. Green manure, a cheap nitrogen source, is considered to increase crop yield and improve soil fertility. For compost, lack of a locally available manure resource is a major problem while animal waste as the main source of manure is not always available. Farmers try their best to find sources of nutrients to increase the soil fertility. Green manures offer the greatest potential as a feasible and cheaper supplement. Utilization of green manure has also been a practical method to improve soil organic matter, nutrients and soil structure. They are normally planted in crop rotation, intercropped or in turn with green leaf manuring.

4.1.1 Green manure on inland saline soil

It is well recognized that legume crops when grown in a cropping system will increase growth and yield of the main crop. Nutrients such as N, P, K, Ca, Mg and micronutrients will be released after incorporation. Utilization of green manure results in increasing adsorption capacity and nutrient availability, and improved soil physical properties (Ladha *et al*., 1988; Roger and Watanabe, 1986). However, suitable species of green manure varied with agro-climatic, soil and water conditions. For example, green manure planted in saline soil is tolerant to salinity and maybe also to acidity and waterlogging. Green manure is a very useful practice for management of salt affected soil; as a source of plant nutrients and a supply of energy to microorganisms. Green manure influences the physical condition of soil favourably, counteracting the unfavourable effects of exchangeable Na (Palaniappan and Budhar, 1992). So green manure is suitable for managing salt-affected soils; as a source of plant nutrients and a supply of energy to soil microorganisms. *Sesbania* and *Aeschynomene* show high potential as green manure crops. They are fast growing plants, high in nitrogen fixation ability and grow well in soil under adverse conditions. Many green manures are based on rice cultivation. They can be used as green leaf manure, or green matter cut and brought from elsewhere to the field for incorporation.

a) Major Characteristics of green manure crop

Good green manure should have the following characteristics (Sratongkam, 1973; Chinapun, 1982; Arunin *et al*., 1988); a fast growing plant and giving high biomass, drought tolerance, a well developed root system, tolerance for disease and pests, easy to incorporate and having rapid decomposition. The green manure should be easy to propagate but also easy to eradicate, to prevent it from turning into a weed. It should lend itself to use as food or forage to allow easy introduction into a cropping system. The nutrients content of green manure that usually used in Thailand are shown in **appendix6**.

b) Role of *Sesbania* and *Aeschynomene* as green manure

Sesbania is a leguminous genus, containing about 50 species. It can be divided in to 3 groups; tree, shrub and perennial crop. Most of these plants are still wild, a few have been discovered and some have been used by farmers in many regions. *S. rostrata, S. cannabina, S. speciosa* and *S. aculeata* are popular species used as green manure. *S. rostrata,* a stem-nodulating legume (**Figure 4.1 and 4.2**), is originally from South Africa and was studied as a green manure for rice in many countries such as Philippines, Laos, India, USA, Japan and also under the saline soils of Thailand. It is particularly sensitive to photoperiod. It is classified as a short day plant with a critical day length of 12-12.5 hrs (Visperas *et al*., 1987). However, *S. bispinosa*, *S. aculeata*, *S. cannabina* and *S. sericea* are not easily identified due to their similar characteristics (Evans and Rotar, 1987). These four species are sometimes classified as *S. cannabina. S. cannabina* is the name usually given to the annual *Sesbania* used in China. However, the *S. cannabina* and *S. aculeata* found in Thailand are evidently different. *Aeschynomene afraspera*, a stem-nodulating legume, has high potential as a new green manure which can be used in a rice-based cropping system. This plant is the same genus as *A. indica* and *A. aspera* which are found in central Thailand.

Sesbania and *Aeschynomene* have low C/N ratios of 16-24 and 13-16, respectively, which means that they easily decompose and release nutrients for the following crop. However, the C/N ratio varies with species, age and locations. They can act as a substitute second crop to maintain long term soil productivity. Numerous studies have shown that *Sesbania* species show high potential as a green manure crop. Two thirds of N from *S. rostrata* will be released to the soil and only one third will be absorbed by plants (Rinaudo *et al*., 1983).

S. rostrata shows the highest potential for use as a green manure in the Northeast. Green manure with soil amendments in particular gave highest yields. Green manure without amendment and fertilizer should be recommended only to the poorest farmers' group while green manure with amendment plus fertilizer should be recommended to the farmer group with slightly better resources to enable them to earn the highest income (Arunin *et al*., 1992a).

Figure 4.1 *Sesbania rostrata*

Figure 4.2 Stem nodules of *Sesbania rostrata*

Many studies showed that *A. afraspera* also has high potential for use as a green manure. However, in northeast Thailand it produced low biomass and low nodulation capacity even it had been inoculated.

In the intercropping system, *Sesbania* was intercropped with rice in an intensive cropping pattern and this demonstrated a saving of time. It was found that N and rice yield increased. However, the density of *Sesbania* is very important as it may have competition or shading effects on the main crop.

S. sesban, *S. grandiflora* and *S. speciosa* are commonly used for green leaf manuring or planting on the bunds and then leaves and branches are cut for incorporation. It was found that this method can increase rice yield. However, due to fewer plants being able to grown on the limited bund areas, biomass for incorporation was inadequate and the contribution of green leaf manure to the following rice crop was not significant, as confirmed by the study of the Soil Salinity Research Section, Land Development Department. Technique and frequency of cutting should be further studied, and the problem of transportation must be solved (Arunin *et al*., 1992b).

Sesbania species are not food plants but flowers and young leaves are consumed as vegetables in *S. grandiflora* and *S. roxburghii* for example, while *S. sesban* and *S. formosa* are used as forage crops. Some perennial *Sesbania* are used as fuel.

c) Tolerance to salinity and flooding

Many *Sesbania* species are able to tolerate adverse soil conditions such as saline, acid, alkaline or drought or flooded conditions. For example in saline soil, *S. rostrata, S. speciosa* and *S. aculeata* will grow satisfactorily from the germination stage to the reproductive stage and produce seeds (Arunin *et al*., 1987a). However, the growth rate tends to decrease with increasing salinity levels. *S. rostrata* and *S. aculeata* are more tolerate to salinity than other species. Four species of *Sesbania* can survive in saline soil of 4-12 dS m^{-1} under both dry and flooded conditions.

S. speciosa and *S. rostrata* develop their ability to tolerate flooding after the seeding stage. Therefore, the seedlings need several weeks of non flooded conditions before they can readily withstand flooding. The basis for flood tolerance in *Sesbania* is the development of parenchyma, a spongy tissue having enlarged cells with large intercellular space. This development allows the plant to avoid anoxia in the root zone (Evans and Rotar, 1987). Flooding tolerance of *S. rostrata* is higher than that of *S. aculeata*, *S. cannabina* and *S. speciosa*, respectively (Arunin *et al*., 1987a).

d) Nitrogen fixation and N-equivalence

The nitrogen fixation capacity of *Sesbania* varies with species, age and environment factors such as soil properties; flooded or dry conditions. *Sesbania*'s ability to fix N extends from the nodules formed by N-fixing rhizobia, which exist symbiotically with the plant. Yields and N accumulation have been widely reported elsewhere for instance, *S. rostrata*, a stem-nodulation legume inoculated with specific rhizobium had 5-10 times more nodules than other species. The specific rhizobium is *Azorhizobium caulinodans* ORS 571, while rhizobium ORS 322 is specific to *A. afraspera*, another stem-nodulating legume (Rinaudo *et al*., 1988). *S. rostrata* showed the highest N-accumulation at 200-267 kg N ha^{-1} when compared among species (Dreyfus *et al*., 1983; Rinaudo *et al*., 1983). It showed a linear increase in N fixation for the period of 35-53 days after germination while *A. afraspera* showed a maximum potential of 423 kg N ha^{-1} (Alazard and Backer, 1987). In infertile rainfed lowland areas of northeast Thailand, N fixation of *S. rostrata* was equivalent to 16 and 372 kg ha^{-1} at 30 to 75 days after germination. The advantages and disadvantages of *Sesbania* spp. are shown in **table 4.1** (Arunin *et al*., 1988).

e) Cultural practice

1) Planting date: April-June is suitable because many species of *Sesbania* such as *S. rostrata* and *S. speciosa* are short day plants which will grow well and allow them to have enough time to grow before flowering.

2) Land preparation: Tillage is needed for better and more uniform growth. Seed can also be broadcasted without tillage and will germinate when enough rain has fallen.

3) Seed rate: Seed sowing at a rate of 30 kg ha^{-1}, however this depends on the quality of seed. For perennial plants, *S. grandiflora* or *S. javanica*, propagation can be done by use of stem and branch cuttings.

4) Seed treatments: Soaking in concentrated sulfuric acid and then rinsing with water is common practice, or soaking in boiling water for 1 minute, or scarification by sand paper are also possible to increase germination rate.

5) Rhizobium inoculation: Seed inoculation at the first planting with rhizobium ORS 571 for *S. rostrata* and the cowpea group of other species, and rhizobium ORS 322 for *A. afraspera*.

6) Planting: Seed can be broadcasted or sown in rows.

7) Incorporation: Plants are usually incorporated 60 days after sowing (**Figure 4.3**) or less than 60 days when they have produced enough biomass. Thamphang (1992)

reported that the biomass of *Sesbania* increased with increasing age, but it produces more fiber at older age thus, causing difficulty for incorporation.

Table 4.1 Advantages and disadvantages of *Sesbania* spp.

Species	Advantages	Disadvantage
S. rostrata	- high biomass - fast growing - root and stem nodulation - can be grown in saline, acid soil, upland and lowland - can be used as forage - 1.53% N-content	- photoperiod sensitive - large plant - difficult to plow in - susceptible to pod-borer infection - indeterminate growth type - inoculation with ORS 571 is needed
S. speciosa	- high biomass - tolerate to insect and drought - can be rationed - used as forage and fodder - 1.4-2.4% N-content	- slow to flower - hard and large stem - photoperiod sensitivity - die if flooded to more than 50 cm - can be damaged by insects in the ripening stage
S. cannabina	- good as intercrop - short stem and can be rationed - high seed yield - can be used as forage and fodder - 1.6-2.4% N-content	- low biomass - pod borer problem
S. aculeata	- tolerate to salinity - tolerate to drought and flooded - 1.6-2.3% N-content	- low biomass - small seed and cracked pod result in difficult to collect seed - hard stem and difficult to plow
A. afraspera	- fast growth - high biomass - short stem and easy to incorporate - stem- nodulating - 2.2-3.3% N-content	- less tolerance in problem soil

Source: Arunin *et al*. (1988)

8) Transplanting: 2-7 days after incorporation or depending on suitable water conditions. For *S. rostrata*, rice can be immediately transplanted after incorporation.

Figure 4.3 Plants are usually incorporated at 60 days after sowing

f) Seed production and seed storage

The extension and adoption of *Sesbania* as a green manure in Thailand is not as successful as in many other countries because there are many problems, especially seed availability and quality. Research on seed production and storage is needed. Some suggestions for seed production are as following (Arunin, 1996).

1) Site selection: Planting sites of slightly fertile soil should be selected, with lowland being preferred to upland in order to produce higher seed yield.

2) Planting date: Date of planting depends on plant characteristics. *S. rostrata* should be grown between July and August while *S. cannabina* can be planted in any month.

3) Seed rate: The appropriate seed rate is 12-18 kg ha^{-1} and inoculation with specific rhizobium strain is recommended. Cuttings from stems can be used for plant propagation.

4) Planting method: Either spacing of 75×25 cm in rows or by broadcasting is commonly practiced. In infertile soil, application of P and K at a rate of 50 kg ha^{-1} is needed with liming also needed in acid soil.

5) Harvesting: Since *Sesbania* is of indeterminate growth type, harvesting may be needed several times. **Figure 4.4** shows *S. rostrata* at seed formation stage. The seed should then be mixed with insecticide before storage.

Figure 4.4 *Sesbania rostrata* at seed formation stage

Seed yields could be increased by increasing plant populations of *Sesbania* (Arunin *et al*., 1989). The Soil Salinity Research Section's study showed that decapitating at 45 days after sowing will increase pod yields.

In cases where planting areas are scarce, plants may be grown on the rice bund or planted between rice rows, however lower seed yield will be obtained. Seed quality is closely related to storage technique. The Soil Salinity Research Section suggested that after drying, seeds should be stored in a cool room and in plastic bags with lime, in order to increase the germination rate (Pongwichian *et al*., 1993). Duration of storage has an effect on the viability of seed, for example with *S. rostrata*, the germination percentage was highest during the 8-12 months after storage and then slowly decreased, while seed of *S. speciosa* is still viable after 15 years.

Empirical studies on the utilization of green manure in saline soil follow:

Green manure is suitable for managing salt-affected soils as a source of plant nutrients and a supply of energy for soil microorganisms (Palaniappan and Budhar,1992; Meelu *et al*., 1994). Numerous studies indicate that members of the leguminous genus *Sesbania* show high potential as a green manure crop in salt-affected soils for rainfed lowland rice systems. In particular, *S. rostrata* L., a stem-nodulating legume, grows well under saline conditions of up to 4-12 dS m^{-1} and also tolerates flooding conditions (Arunin *et al.*, 1987a). Moreover, the crop shows high nitrogen fixation capacity. *S. rostrata* resulted in the highest increases of rice yields when incorporated into saline soils (Drefus *et al.*, 1985; Rinaudo *et al.*, 1983; Anuluxtipun *et al.*, 1992; Thamphang, 1992).

The studies on utilization of *S. rostrata* as a green manure for rice in the saline soils of Thailand were conducted around 30 years ago by the Land Development Department (Arunin *et al.*, 1988). The following are the studies that were conducted by Pongwichian *et al*. (1997; 1998; 2006; 2007).

4.1.2 Effects of *Sesbania rostrata* on rice planting methods and yields of Jackbean (*Canavalia ensiformis*) after rice in saline soils

The study was conducted in inland saline soil at Ban Tahbo, Tawatchaburi, Roi-Et province, northeast Thailand during 1991-1993. This area was of infertile or low fertility saline soil with electrical conductivity (EC_e) of 5.5 dS m^{-1}. This is classified as moderately saline soil, low in total N and available P of 0.07 % and 2.71 mg kg^{-1}, respectively.

Two rice varieties of RD 15 and KDML 105 were planted by transplanting and dry seeded methods with and without *S. rostrata* plantation under a 2×2×2 factorial in a randomized complete block design with 3 replications. Biomass and N-accumulation of *Sesbania*, yield and yield components of rice were recorded. After rice harvesting, jackbean was planted. Biomass and yield were recorded also. Statistical analysis was performed using IRRISTAT to determine the effect of different treatments. Two way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used.

The results showed that *S. rostrata* planted and incorporated for direct seeding and transplanting gave high biomass and N-accumulation at an average of 36.9 t ha^{-1} and 208 kg N ha^{-1} (**Table 4.2**). However, growth of *Sesbania* depended on distribution and amount of rainfall. Utilization of *S. rostrata* showed a higher rice yield average of 3.07 t ha^{-1}, which was 46 % greater than the control treatment (2.13 t ha^{-1}). The direct seeding method gave rice yield of 2.83 t ha^{-1}, higher than those of the transplanting method (2.42 t ha^{-1}). A difference between rice varieties was not found. It was found that the direct seeding method with *S. rostrata* gave a higher rice yield than that of the transplanting method with *Sesbania*, as shown in **table 4.3**. However, rice yield varied with distribution and amount of rainfall. For jackbean after rice, it showed that Jackbean could grow and survive under saline soil and drought conditions with full growth. It was concluded that *S. rostrata* was effective as a green manure in both transplanted and direct seeded rice systems, and could significantly increase yields due to *S. rostrata* giving high biomass and plant nutrients, especially nitrogen, and could result in improving physical properties of soil when incorporated into saline soils (Pongwichian *et al*., 1997).

Table 4.2 Fresh weight (FW, t ha^{-1}) and N-accumulation (kg N ha^{-1}) of *S. rostrata* that was incorporated for rice.

Planting method	**Varieties**	**1991**		**1992**		**1993**		**Average**	
		FW	**N-acc.**	**FW**	**N-acc.**	**FW**	**N-acc.**	**FW**	**N-acc.**
Transplanting	RD 15	29.4	159	19.7	39	55.8	462		
	KDML 105	23.1	119	38.3	116	61.6	403		
Direct seeded	RD 15	25.6	154	23.5	144	38.4	220		
	KDML 105	24.3	124	60.3	171	42.6	385		
Average		25.6	139	35.5	118	49.6	368	36.9	208

Mean of 3 replications (n=3)

After three years of experimentation, it was found that EC_e, decreased from 5.50 to 2.68 dS m^{-1}, while incorporation of *S. rostrata* resulted in increasing soil organic matter (OM), nitrogen (N) and phosphorus (P) from 0.652 to 1.175 %; 0.036 to 0.059 % and 6.35 to 9.23 mg kg^{-1}, respectively as shown in **table 4.4**.

Table 4.3 Effect of *S. rostrata* and planting method on yields of two rice varieties (t ha^{-1}).

Planting method	Varieties	Green manure	
		S. rostrata	**Non GM**
Transplanting	RD 15	3.04±1.38	1.89±0.76
	KDML 105	2.72±1.29	2.01±0.94
Average		2.88±1.21	1.95±0.77
Direct seeded	RD 15	3.47±0.37	2.14±0.92
	KDML 105	3.23±0.11	2.47±0.23
Average		3.35±0.28	2.31±0.62
Average		3.07±0.87	2.13±0.69

Mean of 3 replications (n=3) of 3 consecutive years, Factor of green manure showed a significantly difference by DMRT (P<0.05).

Source: Pongwichian *et al*. (1997)

Table 4.4 Soil chemical properties after three years of experiment.

Green manure	Rice var.	pH (1:1 H_2O)	EC_e (dS m^{-1})	OM (%)	Total N (%)	Available P (mg kg^{-1})
S. rostrata						
Transplanting	RD 15	5.43±1.11	4.93±2.75	1.17±0.31	0.059±0.016	7.58±0.30
	KDML 105	5.28±0.92	2.03±1.40	1.09±0.10	0.055±0.005	7.89±0.59
Direct seeded	RD 15	5.15±0.85	4.10±1.57	1.27±0.15	0.064±0.008	12.79±5.88
	KDML 105	4.60±0.48	3.78±1.07	1.17±0.29	0.059±0.015	8.67±1.05
Average		5.11±0.84	3.71±1.95	1.18±0.22	0.059±0.011	9.23±3.45
Non GM						
Transplanting	RD 15	6.20±0.72	1.35±0.44	0.33±0.22	0.030±0.002	5.71±1.59
	KDML 105	5.98±0.30	1.30±0.24	0.61±0.14	0.031±0.007	5.46±0.76
Direct seeded	RD 15	5.85±0.84	2.05±0.97	0.81±0.03	0.040±0.001	6.83±1.21
	KDML 105	5.90±0.94	1.88±0.39	0.86±0.09	0.043±0.004	7.39±1.06
Average		5.98±0.68	1.64±0.62	0.65±0.25	0.036±0.007	6.35±1.33

Mean of 3 replications (n=3)

4.1.3 Optimum incorporation age of *Sesbania rostrata* as green manure for rice in saline soil

The study was conducted in a farmer's field of inland saline soil at Ban Bokae, Prayuen district, Khonkaen province, northeast Thailand during 1996-1997. The soil was moderately saline soil (EC_e = 7.76 dS m^{-1}) and low in fertility. It was low in soil organic matter, total N, available P and K of 0.38 %, 0.037 %, 7.7 and 37.8 mg kg^{-1}, respectively.

The objectives were to study the optimum incorporation age of *S. rostrata* for highest biomass and N-accumulation and to compare the effect of green manure and chemical fertilizer on growth and yield of rice in saline soil. The experimental design was a randomized complete block with 3 replications. Incorporation age of 40, 45, 50, 55, 60 and 65 days after sowing (das) were studied and compared to utilization of urea at rate 50 kg N ha^{-1}. Statistical analysis was performed using IRRISTAT to determine the effect of different treatments. One way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used. Data of growth and N-accumulation of *Sesbania* were collected. Data of yield and yield components were recorded also. The effect of incorporation of *S. rostrata* on the change of soil properties was studied.

The results showed that growth and N-accumulation of *Sesbania* increased with increasing age. *Sesbania* at age of 65 das gave highest average biomass of 15.0 t ha^{-1}. And *Sesbania* at age of 65 das gave highest N accumulation 131 kg N ha^{-1}. It was found that utilization of *Sesbania* increased rice yield but it was not significantly different from the chemical fertilizer application. Utilization of 65 das *Sesbania* gave the highest average rice yield of 1.77 t ha^{-1} but it was not significantly different to the other incorporation ages as shown in **table 4.5**. So it could be concluded that biomass and nitrogen accumulation increased with increasing incorporation age. The response of rice yield was similar to biomass, rice yield increased with increasing incorporation age (Pongwichian *et al*., 1998).

Two years of rice cultivation in saline soil resulted in decreasing soil electrical conductivity (EC_e) while organic matter and available P increased. And it was found that total N and available K slightly decreased (**Table 4.6**).

Table 4.5 Effect of incorporation age of *Sesbania rostrata* on biomass, N-content, N-accumulation and rice yield in saline soils when compared to chemical fertilizer.

Incorporation age	Biomass ($t\ ha^{-1}$)		N content (%)		N-accumulation ($kg\ N\ ha^{-1}$)		Rice yield ($t\ ha^{-1}$)	
	1996	1997	1996	1997	1996	1997	1996	1997
40 days	1.6d	6.0	2.0	1.5	20.8	5.3	0.72	1.76
45 days	2.7d	12.0	1.8	2.0	60.9	8.4	1.33	2.23
50 days	5.4cd	11.3	2.5	2.3	66.9	29.0	0.70	1.68
55 days	9.1bc	12.2	3.0	2.2	63.9	66.1	1.07	1.98
60 days	114.0ab	13.2	2.9	2.3	73.9	95.6	0.95	2.08
65 days	17.8a	12.1	3.4	2.9	89.4	173.1	1.16	2.41
control	-	-	-	-	-	-	1.00	2.09
Urea	-	-	-	-	-	-	1.10	2.38
F-test	**	ns	-	-	-	-	ns	<1
CV (%)	33	30	-	-	-	-	23	28

In the column, mean followed by different letters indicates difference by DMRT (P<0.05).

Table 4.6 Effect of incorporation of *S. rostrata* on the change of soil properties.

Treatments	pH	EC_e ($dS\ m^{-1}$)	OM (%)	Total N (%)	Avai. P ($mg\ kg^{-1}$)	Avai. K ($mg\ kg^{-1}$)	CEC ($me\ 100\ g^{-1}$)
Control	4.30	2.80	0.71	0.037	21.0	23.3	1.83
Urea	4.73	3.26	0.63	0.033	22.7	25.7	2.06
40 days	4.43	3.05	0.54	0.030	13.7	23.3	1.92
45 days	4.37	3.98	0.56	0.030	12.7	21.0	1.92
50 days	4.30	3.68	0.63	0.037	12.7	19.0	1.87
55 days	4.43	4.02	0.79	0.043	15.3	39.0	2.28
60 days	4.40	3.17	0.79	0.040	25.3	23.0	2.19
65 days	4.57	4.13	0.81	0.040	14.0	26.0	1.93
Average	4.44	3.51	0.68	0.036	17.2	25.0	2.00

Mean of 3 replications (n=3)

4.1.4 Effect of soil amendment on rice yields in saline soils

The third study was conducted at Ban Muangpia, Ban Phai district, Khon Kean province during 2004-2006. An observation trial compared the effects of soil amendments and farmer practice on yields. Farmers in Thailand use many kinds of soil amendments such as farmyard manure (FYM), compost, green manure and chemical fertilizer. In different areas, farmers use different amendments. Therefore many kinds of amendments and farmer practices (chemical fertilizer) were compared. These amendments were fertilizer (based on soil analysis), *S. rostrata*, liquid organic fertilizer, rice straw, farmyard manure and application of everything. Four samples of rice yield were collected and the average values were analyzed. For the first year, it was found that farmer practices with the incorporation of *S. rostrata* gave a high yield which was almost the same as the application of everything (**Table 4.7**).

For the second year, rice production was higher when compared to the first year a similar trend was found. Application of everything gave the highest rice yield, higher than the use of *S. rostrata* (**Table 4.7**). However, application of everything is not practical whereas use of *S. rostrata* can be done by farmers, so use of *S. rostrata* is suitable for rice in saline soil.

Table 4.7 Effect of soil amendment on rice yields in saline soils (t ha^{-1}).

Treatments	Year 2005	Year 2006
T1. Farmer practice (FP)	0.50a	2.54c
T2. Complete (application of everything)	1.26a	4.70a
T3. Chemical fertilizer based on soil analysis	0.47a	3.35bc
T4. FP + Green manure	1.26a	3.76b
T5. FP + Liquid organic fertilizer	1.17a	3.36bc
T6. FP + Rice straw incorporation	0.58a	3.08bc
T7. FP + Farmyard manure	0.68a	3.48bc

In the column, mean followed by different letters indicates difference by DMRT (P<0.05).

4.1.5 Effect of soil amendment and rice cultivation on salt movement in the open ditch system of severely saline soil

The fourth study was carried out in severely saline soil at Muangpia subdistrict, Khon Kaen province during 2001-2004. The soil was a severely saline soil with EC_e of 23.9 dS m^{-1}. This soil had low soil organic matter, total N and available P of 0.2 %, 0.01 % and 4.2 mg kg^{-1}, that it was a low fertility soil. The objectives were to study the effect of soil amendments and rice cultivation on salt movement, and to study the effect of soil amendments on growth and yields of rice. The use of compost, farm yard manure, rice husk (at rate of 12.5 t ha^{-1}) and *S. rostrata* (31.3 kg ha^{-1}) were studied under a randomized complete block design with 6 replications. Statistical analysis was performed using IRRISTAT to determine the effect of different treatments. One way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used.

A variation of rice yields was found in the first year of experiment due to the effect of high salinity in this area. The use of *S. rostrata* gave the highest rice yield of 468 kg ha^{-1}. The effects of soil amendments were shown in the second and third year of experiments. The use of farm yard manure gave the highest rice yields of 1,355 and 1,047 kg ha^{-1} in the second and third year, respectively. The use of *S. rostrata*, rice husk and compost gave lower yields of 740, 565 and 288 kg ha^{-1}, respectively (**Table 4.8**).

Table 4.8 Effect of soil amendments on rice yields (kg ha^{-1}) in severely saline soils.

Soil amendments	**Rice yields**		
	Crop season 1	**Crop season 2**	**Crop season 3**
Compost	211	1,177	288b
Farmyard manure	442	1,355	1,047a
Rice husk	373	1,027	565ab
S. rotrata	468	1,236	740ab
F-test	ns	ns	*

In a column, mean followed by a common letter were not different by DMRT 0.05.

Rice cultivation with soil amendments in severely saline soil resulted in decreasing soil electrical conductivity (EC_e) from 23.9 dS m^{-1} to 3.0, 3.1, 3.3 and 3.8 dS m^{-1} (all slightly saline soil) in the case of compost, farmyard manure, rice husk and *S. rostrata*, respectively. Rice cultivation on the plant bed resulted in salt migration to the subsoil (**Table 4.9**).

In addition, it was found that rice cultivation in severely saline soil under open ditch system resulted in salt movement to sub-soil. The EC_e and soluble Na increased with increasing soil depth. The use of compost increased soluble Na from 26.2 cmol l^{-1} to 66.4 cmol l^{-1} at depths of 0-30 and 90-120 cm, respectively, While the use of farmyard manure, rice husk and *S. rostrata* increased soluble Na from 28.4, 33.0 and 37.9 cmol l^{-1} to 67.6, 37.6 and 67.3 cmol l^{-1} at depth of 0-30 and 90-120 cm, respectively (Pongwichian *et al*., 2006). It could be concluded that, in general, *Sesbania* has been found to be effective in slightly to moderately saline soils. Although it can be used in severely saline soil, biomass was lower and resulted in lower yields.

Table 4.9 Effect of soil amendments on soluble Na (cmol l^{-1}) and EC_e (dS m^{-1}) at the depth of 0-30 cm.

Soil amendments	**Soluble Na**				**EC_e**			
	Before	**Year 2001/02**	**Year 2002/03**	**Year 2003/04**	**Before**	**Year 2001/02**	**Year 2002/03**	**Year 2003/04**
Compost	317.3	74.7	41.1	26.2±3.2	23.9	9.0	4.6	3.0±0.4
Farmyard manure	317.3	92.2	62.0	28.4±0.6	23.9	13.0	6.8	3.1±0.4
Rice husk	317.3	101.4	28.0	33.0±9.5	23.9	11.0	3.5	3.3±0.7
S. rostrata	317.3	74.7	36.7	37.9±5.6	23.9	8.1	4.3	3.8±0.5

Mean of 6 replications (n=6)

4.1.6 Conclusion

Sesbania rostrata, if used as a green manure has high potential to mitigate salinity in inland salt-affected soils (for rainfed lowland rice systems). Application of green manures increased rice yields by up to 30 % while soil electrical conductivity decreased. After incorporation, green manure plant will decompose and nitrogen will be released from the N- transformation processes of mineralization. Factors on decomposition and mineralization include N content C/N ratio and lignin content, which depend on species and age of the green manner crop (Meelu *at al.*, 1994). Anuluxtipun *et al*. (1992) and Arunin *et al*. (1994) reported that *S. rostrata* had the highest NH_4^+- N at 7-28 days after incorporation. While Nagarajah (1988); Becker *et al*. (1990) and Diekmann (1990) reported that leguminous green manure namely *S. rostrata* decomposed rapidly following incorporation in tropical flooded soil. Nitrogen as ammonium N-form (NH_4^+- N) must be partly attributed to higher N-accumulation in *S. rostrata* which resulted in higher N-mineralization and subsequently more available nitrogen to the rice crop. And incorporation green manner can increase the soil nitrogen pool and result in increasing soil organic matter content. The increase in soil organic matter content, which enhanced the porosity of soil (Nakaya and Motomura, 1984). This would promote for downward movement of water and leaching of salt from soil surface. Finally, this results in decreasing of soil electrical conductivity. These results corroborated the earlier findings reported by Arunin *et al.* (1992a), Arunin *et al.* (1994) and Pongwichian and Arunin (1993a), and since 1982 have subsequently led to widespread advocacy of *S. rostrata* by the Land Development Department, and almost universal adoption by affected farmers. However, utilization of *S. rostrata* as a green manure has remained constrained by factors such as insufficient availability of seed, low seed germination, photoperiod sensitivity, incorporation method difficulty for rice transplanting after incorporation and increased variable costs (especially labour).

4.2 Utilization of salt tolerant species in coastal saline soil

4.2.1 Outline of experimental area

Coastal salt-affected soils originated from seawater scattered along the coast. In Thailand, coastal saline soils cover an area of 0.425 million ha, most of which is not suitable for agriculture (Office of Soil Survey and Land Use Planning, 2006). These areas are subject to tidal influences and brackish or sea water intrusion. These soils are very young heavy clay or silty clay with little profile development. They are very saline and most of them are flooded during spring tides only. Factors limiting plant growth include not only salinity but also potential acidity and degree of ripening of the soil (de Glopper, 1971).

Rehabilitation attempts should take into account local land use practices and the land condition. One way to rehabilitate saline soils is to utilize salt-tolerant plant species. In areas of high salinity which are unsuitable for economic crops, many other plants can still be grown. Arunin (1992) concluded that management of coastal salt-affected soils needs to cope with the specific characteristics of the soil, crop and water regimes. Rice cultivation is common in these areas with salt-tolerant rice varieties. Economic salt tolerant crops such as tomato, cabbage, sweet potato, corns, cantaloupe and taro were suggested with organic amendments and chemical fertilizer application. However, farmers have also used indigenous technologies to reclaim their lands, so called, soil ridging of approximately 6-7 metres wide for cultivating coconuts or other crops.

Yuvaniyama and Arunin (1996b) found that Dixie grass (*Sporobolus virginicus* coarse type), Smyrna grass (*Sporobolus virginicus* smooth type), *Spartina patens*, *Distichlis spicata*, Kallar (*Leptochloa fusca*), and *Atriplex spp.* are well adapted to the highly saline soils of northeastern Thailand. On the other hand, Im-Erb *et al*. (1994) reported that *S. patens* had a higher survival rate than *Panicum repens*, Dixie grass, and Smyrna grass in coastal saline soils.

The development of plants for avoidance or tolerance salinity problem depends on plant species. *S. virginicus* can store salt in special structured as salt gland with ion secretion, this result in avoiding their toxicity. Shoot Na^+ and Cl^- accumulation was controlled not exceeding levels required for osmotic adjustments (Marcum and Murdoch, 1992). While *D. spicata* accumulated proline rapidly following initiation of NaCl-induce stress (Ketchum *et al*., 1991). *S. patens*, an intertidal C_4 grass, grows in the upper salt march and tolerance coastal seawater salinity. Wu and Seliskar (1998) reported that the mechanism of salt tolerance was the response of plasma membrane H^+ -ATPase to NaCl . PM H^+-ATPase activity significantly increased under salt stress.

So the study on "**Utilization of salt tolerant species for rehabilitation of coastal saline soil in Petchaburi province Thailand"** (Pongwichian *et al*., 2014a) was conducted at the Sirindhorn International Environmental Park, Cha-am district, Petchaburi province between April 2010 and September 2011. The objectives of our research were to compare the growth of different halophytes in saline soils in coastal areas and to investigate the effect of halophytes on changes in the chemical properties of saline soils and their suitability for the rehabilitation of coastal saline soils.

4.2.2 Experimental methods

The research was carried out using a randomized completed block design with four replications.. The tested halophytes that consisted of exotic halophytes were imported from the United States of America (**Figure 4.5**):

(a) Dixie grass (*Sporobolus virginicus*, coarse type)

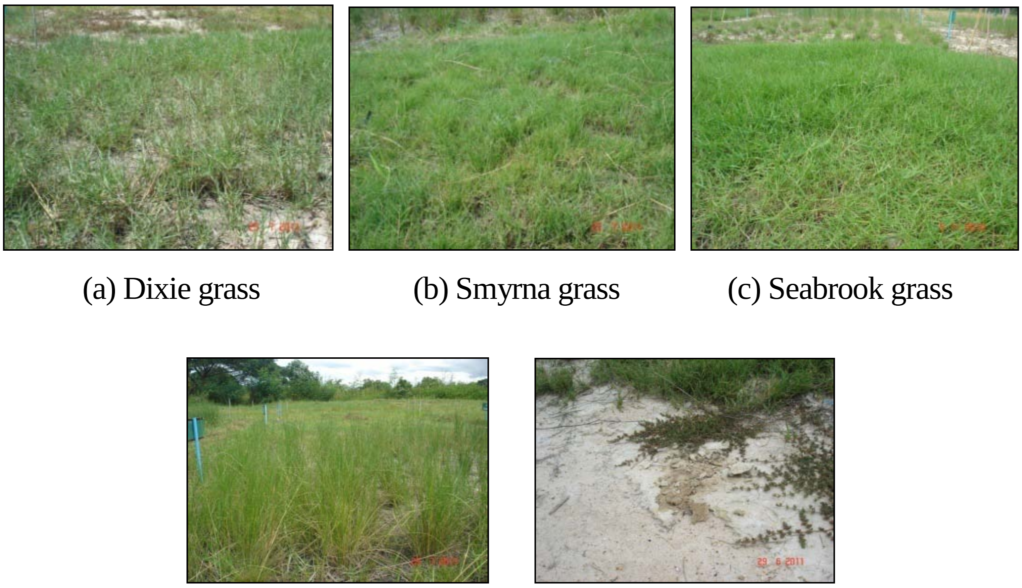
(b) Smyrna grass (*Sporobolus virginicus*, smooth type)

(c) Seabrook grass (*Distichlis spicata*)

(d) Georgia grass (*Spartina patens*)

(e) Naturally-grown grasses (non-halophyte block)

Each experimental block measured 3×3 m. Farmyard manure at the rate of 12.5 t ha^{-1} was applied at soil preparation. On August 20th 2010, the 4 halophyte species were planted with plant spacing of 30×30 cm. Weed and pest controls were also employed.



(a) Dixie grass (b) Smyrna grass (c) Seabrook grass

(d) Georgia grass (e) Natural grass

Figure 4.5 Four species of salt tolerant plants and control plot (natural grass)

Data collection

a) Soil Data: Soil samples were taken at a depth of 0-30 cm to determine the soil pH according to Peech (1965), soil electrical conductivity (EC_e) according to Rhoades (1982), soil organic matter according to Walkley and Black (1934), available P according to Bray and Kurtz (1945), available K according to Chapman (1965), and soluble Na according to Rhoades (1982).

b) Plant Data: Data on survival rates and biomass were collected 3 times (December 2010, June 2011, and September 2011). The concentration of total N was determined according to AOAC (1990), total P according to Barton (1948) and total K and total Na according to Jackson (1958).

Statistical analysis was performed using STATISTIX (version 8.0) to determine the effect of different treatments. One way ANOVA (analysis of variance) was used to investigate the level of significance (P<0.01, 0.05). To compare the means, LSD (Least Significant Difference) was used.

4.2.3 Results and discussion

a) Survival rates

Among the 4 halophyte species planted on August 20th, 2010, Dixie grass showed the highest survival rate, though it was only slightly higher than Smyrna grass and Georgia grass, while Seabrook grass had the lowest survival rate (**Table 4.10**). This result differed from that of Im-Erb *et al*. (1994) who reported that Georgia grass had a higher survival rate than Dixie grass and Smyrna grass. Furthermore, Yuvaniyama and Arunin (1992a) reported that Dixie grass and Smyrna grass can show survival rates of up to 100 % at a salinity of 40 ppt of NaCl. While Gallagher (1979) reported that *Sporobolus virginicus* is a highly salt-tolerant plant that can survive in media with salinity of 30 %. The 4 species could survive because of their superb ability to excrete excess salt through their leaves.

Table 4.10 Survival rate in 2010, fresh and dry weight of salt tolerant species on coastal saline soil.

Salt tolerant species	**Survival rate (%)**			**Weight ($t\ ha^{-1}$)**	
	8 September	**5 November**	**28 December**	**Fresh weight**	**Dry weight**
Dixie grass	100.0	99.3	99.3	6.9	3.0
Smyrna grass	99.3	97.2	97.2	4.9	2.1
Seabrook grass	91.0	83.3	83.3	19.8	12.2
Georgia grass	94.4	94.4	93.1	8.8	3.9
LSD	9.5	8.8	9.1	6.6	4.3
C.V. (%)	6.4	6.1	6.3	42.3	52.9

b) Fresh and dry weight

Data on biomass were collected 3 times in December 2010, June 2011, and September 2011. Throughout the research period, Seabrook grass produced the highest fresh and dry weights of 19.8 and 12.2 t ha^{-1}, respectively which were significantly higher than for Georgia grass, Dixie grass and Smyrna grass, respectively (**Table 4.10**). However, the difference in fresh and dry weight also depends on the phenotype of the species.

c) Nutrient accumulation (**Table 4.11**)

Nitrogen: Seabrook grass had the largest accumulation of N, at both 6 months (38.4 kg ha^{-1}) and 14 months (57.8 kg ha^{-1}), which were higher than for Georgia grass, Dixie grass and Smyrna grass, respectively.

Phosphorus: Seabrook grass accumulated the highest amounts of P, at both 6 months (6.8 kg ha^{-1}) and 14 months (10.8 kg ha^{-1}), which were greater than in Georgia grass, Smyrna grass and Dixie grass, respectively.

Potassium: Seabrook grass accumulated the highest amounts of K, at both 6 months (24.5 kg ha^{-1}) and 14 months (38.8 kg ha^{-1}), which were greater than in Dixie grass, Smyrna grass and Georgia grass, respectively.

Sodium: The Na accumulation of Seabrook grass at both 6 months and 14 months was 36.9 kg ha^{-1}, which were greater than in Georgia grass, Dixie grass and Smyrna grass, respectively.

The results suggested that the N, P, K, and Na concentrations varied with species, while the accumulation or uptake of N, P, K, and Na varied with the biomass of the specific species.

d) Changes in soil chemical properties (**Table 4.12**)

Soil pH: The average initial pH of the experimental plots was 7.15. However, all experimental plots showed an increase in pH by the end of the experiment, especially the Dixie grass plot which had a pH value increase from 7.40 to 7.92.

Table 4.11 Nutrient content (%) and nutrient uptake (kg ha^{-1}) of salt tolerant species at 6 and 14 months.

Salt tolerant species	Age	N		P		K		Na	
		Cont.	Uptake	Cont.	Uptake	Cont.	Uptake	Cont.	Uptake
Dixie grass	6	0.95±0.05	6.7±0.37	0.24±0.19	1.7±1.34	0.53±0.03	3.76±0.18	0.67±0.37	4.7±0.58
	14	0.97±0.12	13.4±1.65	0.16±0.05	2.2±0.70	0.68±0.26	9.4±3.63	0.65±0.38	9.0±5.29
Smyrna grass	6	1.12±0.29	5.1±1.33	0.39±0.37	1.78±1.66	0.80±0.16	3.6±0.72	0.80±0.19	3.6±0.88
	14	0.93±0.27	11.6±3.32	0.24±0.17	3.0±2.06	0.60±0.11	7.5±1.35	0.60±0.41	7.5±5.11
Seabrook grass	6	1.02±0.08	38.4±2.94	0.18±0.00	6.8±0.19	1.90±0.09	71.43±3.26	0.98±0.34	36.9±12.92
	14	0.97±0.08	57.8±4.55	0.18±0.05	10.8±3.10	0.65±0.27	38.8±15.95	0.62±0.40	37.10±23.91
Georgia grass	6	0.81±0.06	11.7±0.81	0.30±0.32	4.3±4.66	0.73±0.08	10.47±1.09	0.68±0.23	9.8±3.36
	14	1.00±0.13	7.6±0.97	0.15±0.02	1.1±0.18	0.58±0.21	4.4±1.57	0.68±0.36	5.2±2.75

Mean of 4 replications (n=4)

Soil Electrical Conductivity (EC_e): The EC_e values of all experimental plots were initially between 6.85 and 12.46 dS m^{-1}, which could be classified as moderately to severely saline. After the experiment was completed, all plots showed a decreases in EC_e, especially the plot with Seabrook grass whose EC_e decreased from 12.46 to 6.02 dS m^{-1}. The characteristics of specific species may affect the EC_e value. Seabrook grass has a creeper form that helps preserve soil moisture and reduces the accumulation of salt on the soil surface. These characteristics of Seabrook grass may affect its EC_e so that it decreased more than in the other species, which is consistent with the observations of Yuvaniyama and Arunin (1996a) in their research. In contrast, Sakai *et al.* (2012) reported that the levels of Na, Cl and EC_e in all test plots decreased after the growth of halophytes.

Soil Organic Matter: The organic matter of the soil before the experiment was low; however, it had increased when measured at the end of the experiment, especially in the Seabrook grass plot where organic matter increased from 0.52 to 1.32 %.

Available Phosphorus: The amount of available P increased after the experiment, especially in the Seabrook grass plot where the available P increased from 40 to 226 mg kg^{-1}.

Available Potassium: There was a general decrease in the amount of available K after the experiment, with an exception of the non-halophyte control plot with natural-grown grasses where the available K increased slightly.

Soluble Sodium: The soil in the Dixie grass, Smyrna grass, and Seabrook grass plots showed decreases in soluble sodium. This may have been a result of the species growth characteristics that helped to cover the soil surface and their mechanism to absorb salt from the soil and excrete excess salt through the stomatal leaves, thus reducing soluble sodium in the soil. This observation is consistent with Yuvaniyama and Arunin (1996a). On the other hand, the amount of soluble sodium in the Georgia grass and the non-halophyte blocks increased. Plantation salt tolerant crops will provide green cover and result in improve environment. Soil fertility and organic matter were increased. The penetrating root would enhance for downward movement of water and leaching of salt from soil surface.

Table 4.12 Effect of salt tolerant species on change of soil properties.

Salt tolerant species	pH		EC_e (dS m^{-1})		Organic matter (%)	
	Before	After	Before	After	Before	After
Dixie grass	7.15±0.24	7.92±0.13	6.85±2.60	2.75±0.55	0.46±0.04	0.85±0.10
Smyrna grass	7.30±0.08	7.85±0.29	8.95±4.31	3.31±2.06	0.48±0.10	0.98±0.36
Seabrook grass	7.13±0.24	7.52±0.30	12.46±8.86	6.02±6.60	0.52±0.07	1.32±0.61
Georgia grass	7.10±0.08	7.78±0.15	5.58±2.35	5.12±3.00	0.45±0.05	0.88±0.43
Natural grass	7.08±0.10	7.78±0.34	7.35±5.75	5.70±6.83	0.60±0.18	0.95±0.37
F-test		ns		ns		ns
CV (%)		3		100		110

Table 4.12 (cont.)

Salt tolerant species	Available P (mg kg^{-1})		Available K (mg kg^{-1})		Soluble Na^+ (m mol l^{-1})	
	Before	After	Before	After	Before	After
Dixie grass	11.3±4.0	33.7±18.6	240±5.7	188±9.5	60.1±23.5	28.7±3.9
Smyrna grass	16.8±3.30	86.6±62.4	215±28.6	200±37.2	81.0±42.6	38.2±23.0
Seabrook grass	40.3±30.0	225.8±119.0	229±31.2	170±41.9	109.8±79.4	63.5±73.0
Georgia grass	25.5±14.6	125.0±106.6	199±33.5	171±37.8	49.6±23.0	61.6±41.7
Natural grass	28.3±22.6	135.3±97.8	209±21.8	213±64.6	64.9±46.1	68.2±90.3
F-test		ns		ns		ns
CV (%)		42		89		22

4.2.4 Conclusions

- Dixie grass showed the highest survival rate while Seabrook grass had the highest growth, highest fresh and dry weights, and the best nutrient accumulation especially of nitrogen and sodium.

- Growing Seabrook grass resulted in a greater reduction in electrical conductivity and sodium in the soil than from planting the other grasses or allowing grasses to grow naturally. Seabrook grass also seemed to improve the soil fertility more than the other grasses.

4.3 Utilization of organic fertilizer in central plain saline soil

4.3.1 Outline of experimental area

In central Thailand, salt affected soil covers an area of 36,096 ha which has been generally developed from old marine sediments (Hattori and Takaya, 1987). Rice and sugarcane cultivation are common, although yields are generally low. Amount of farmer changes from rice and sugarcane to higher income cash crops. Numerous studies have indicated that selection of salt-tolerant varieties, mulching for conserve soil moisture, application of organic amendments (green manure, compost, farmyard manure) for improve soil fertility and drip irrigation for increasing the efficiency of irrigation could increase crop yields. Successful production of asparagus and cantaloupe using soil amendments (compost, husk ash, bagasse and rice husk) was reported by Arunin *et al.* (1995b), while Hongnoi *et al*. (1999) reported that the use of drip irrigation in Kampangsaen soil series for asparagus resulted in increased yields in saline soils because drip irrigation is the most effective irrigation. Furthermore, utilization of green manure to increase soil fertility for broccoli cultivation has also been studied.

For ways to increase broccoli yields in saline soil, Pongwichian *et al.* (2001) reported the study of "**Effect of planting methods, mulching and seedling age on yields of Broccoli in central plain saline soil**" as follows. This study was carried out for two years under randomized complete block design (by factorial arrangement) with 3 replications. Three factors were:

1) Planting methods were flat and mound planting.

2) Materials for mulching were control, rice husk and plastic sheet.

3) Two seedling ages of 25 days and 35 days.

Statistical analyses were performed using IRRISTAT to determine the effect of different treatments. One way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used. The first year (1999), it found that the mound planting method with seedlings age 25 days gave highest yields of Broccoli (**Table 4.13**). While in the second year (2000), for the flat planting method, mulching had no effect, but mulching showed higher yields in the mound planting method (**Table 4.14**). However, socio-economic considerations such as farmer acceptance and market access must also be taken into account in making such recommendations.

Table 4.13 Effect of planting methods, mulching and seedling age on yields of Broccoli in 1999 (t ha^{-1}).

Mulching	Planting method	
	Flat planting	**Mound planting**
Seedling age 25 days		
Control	3.71a	4.87a
Rice husk	0.67b	0.64b
Plastic sheet	2.52a	2.04b
Seedling age 35 days		
Control	2.74a	No data
Rice husk	0.78b	0.90b
Plastic sheet	1.52a	1.03b

In the columns, mean followed by different letters indicate differences by DMRT (P<0.05)

Table 4.14 Effect of planting methods, mulching and seedling age on yields of Broccoli in 2000 (t ha^{-1}).

Mulching	Planting method	
	Flat planting	**Mound planting**
Seedling age 25 days		
Control	5.64a	5.58a
Rice husk	4.93a	3.07b
Plastic sheet	4.87a	5.93a
Seedling age 35 days		
Control	4.96a	4.34a
Rice husk	4.63a	3.55a
Plastic sheet	4.99a	4.79a

In the columns, mean followed by different letters indicate differences by DMRT (P<0.05)

Besides the study on vegetables, Pongwichian *et al.* (2007) also reported the study on "**Effects of soil amendments on yield of sugarcane in central plain salt affected soil**". In saline condition, the high accumulation Na^+ in leaves causes the toxic effect to plant. For sugarcane, yellow and necrosis leaves are presented. However, there is some sugarcane vanities can survive and grow in this area. Panichponpun (2011) reported that the expression of the vacuolar Na^+/H^+ antiproter gene (*So*NH X1) is the mechanism of sugarcane to defense themselves from the high salt. This was found in sugarcane cultivars K 84-200 and KPS 94-13 when planted in high concentration of NaCl.

This study was carried out for three years under saline and infertile soils (EC_e 8.81 dS m^{-1}). The experimental design was strip plot with 3 replications. Soil amendments of control, *Sesbania rostrata,* compost and farmyard manure were studied. Sugarcane varieties were K 84-200, Utong-3 and KPS 94-13. Statistical analyses were performed using IRRISTAT to determine the effect of different treatments. Two way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used.

It was found that use of farmyard manure which had more plant nutrients was the superior treatment, leading to higher yields than those obtained from treatments of compost and *S. rostrata* green manure in all three years of the experiment (**Tables 4.15 and 4.16**). From these results, it was shown that *S. rostrata* is not suitable for use as a green manure for field crops. Use of farmyard manure also tended to show higher cane juice quality. The results showed that soil amendments resulted in higher levels of organic matter, available phosphorus and potassium whereas soil electrical conductivity (EC_e) tended to decrease due to the application of organic fertilizer improve both plant nutrients and physical properties of soil.

Table 4.15 Effects of soil amendments on yield of sugarcane (t ha^{-1}) in 2004.

Soil amendments	Varieties of sugarcane		
	K 84-200	**Utong-3**	**KPS 94-13**
Control	24.1±12.9a	24.3±6.1a	18.6±6.4a
S. *rostrata*	11.5±13.0a	28.3±36.8a	54.0±41.2a
Compost	39.5±42.9a	44.4±48,2a	24.4±18.7a
Farmyard manure	34.4±12.6a	36.6±8.1a	19.1±19.4a

In the column, mean followed by different letters indicates difference by DMRT (P<0.05).

cv (varieties) = 127.5 % ; cv (soil amendments x varieties) = 62.6 %

Table 4.16 Effects of soil amendments on yield of sugarcane (kg ha^{-1}) in 2005.

Soil amendments	Varieties of sugarcane		
	K 84-200	**Utong-3**	**KPS 94-13**
Control	53.6±12.2	63.4±17.2	62.1±13.8
S. *rostrata*	29.5±17.5	56.8±38.2	47.3±42.8
Compost	75.6±35.9	67.3±37.2	69.5±12.4
Farmyard manure	77.1±14.7	103.0±33.9	84.0±27.3

cv (varieties) = 37.7% ; cv (soil amendments x varieties) = 33.4%

Comparison	*LSD (5%)*	*LSD (1%)*
2 – A mean at each B	*6.853*	*9.929*
2 – A	*4.580*	*6.938*

Physic nut or purging nut (*Jatropha curcas* L.) is a shrub that can grow well under drought conditions. Generally, it is distributed in the arid and semi-arid areas of South America and in tropical areas. It is considered an energy crop. Physic nut can adapt and grow in problem soils such as lateritic soil, sandy soil and saline soil (Gao *et al*., 2008).

Many studies in Thailand showed that physic nut produces low yields. Soil improvement is needed to increase the yield. However, little information on the effect of organic fertilizer on yields has been reported. Silpachai *et al*. (2009) reported that the application of VA-mycorrhizal fungus with organic fertilizer and phosphorus increased physic nut yields. Sukkarin (2008) found that the application of chemical fertilizer showed similar yields to treatment of an application of chemical fertilizer with organic fertilizer; however the yield was higher than the control plot.

So the study on "**Effect of organic and chemical fertilizer on growth and yield of Physic Nut (*Jatropha curcas* L.) in slightly saline soil"** (Pongwichian *et al*., 2014b) was conducted in an experimental field of the Suphanburi Agricultural Research and Development Center, U-thong district, Suphanburi province (**Figure 4.7**) during 2009-2011 where the soil was slightly saline with an electrical conductivity (EC_e) range of 1.33-2.90 dS m^{-1}. The soils were classified as Kamphaeng Saen soil series (fine-silty, mixed, active, isohyperthermic Typic Haplustalfs). The objectives of the research were to study the appropriate management of slightly saline soil in the central plain of Thailand to increase physic nut yield and to study the effect of soil amendments on changes in the soil chemical properties.

4.3.2 Experimental methods

The experimental design was a randomized complete block design with 3 replications. The 10 treatments were as follows.

T1 = Control

T2 = Chemical fertilizer, (15-15-15) at a rate of 156.25 kg ha^{-1}

T3 = Compost, 2 kg $plant^{-1}$ $year^{-1}$

T4 = Compost, 4 kg $plant^{-1}$ $year^{-1}$

T5 = Farmyard manure, 2 kg $plant^{-1}$ $year^{-1}$

T6 = Farmyard manure, 4 kg $plant^{-1}$ $year^{-1}$

T7 = Compost, 2 kg $plant^{-1}$ $year^{-1}$ + bio-extract, 3.125 l ha^{-1}

T8 = Compost, 4 kg plant^{-1} year^{-1} + bio-extract, 3.125 l ha^{-1}

T9 = Farmyard manure, 2 kg plant^{-1} year^{-1} + bio-extract, 3.125 l ha^{-1}

T10 = Farmyard manure, 4 kg plant^{-1} year^{-1} + bio-extract, 3.125 l ha^{-1}

Remark:

1) For treatments 2-10, chemical fertilizer (15-15-15 of N-P_2O_5-K_2O) at a rate of 156.25 kg ha^{-1} was applied.

2) Compost showed N, P and K content of 2.40, 3.37 and 2.62 %. While farmyard manure showed N, P and K content of 1.04, 1.08 and 1.31 %, respectively.

3) Bio-extract is biological extraction made from fresh vegetable waste and it was fermented and digested by effective microorganisms (Microbial Activator Super LDD 2). The bio-extract was diluted with water to 1:500 before spraying once per month.

a) Cultivation management

At the experimental field of the Suphanburi Agricultural Research and Development Center, U-thong district, Suphanburi province (**Figure 4.6**). Thirty experimental plots (6×8 m) were set up. The rate and type of soil amendments were applied according to the treatments. Plants were grown by transplanting cuttings at a spacing of 2×1 m (**Figure 4.7**). Conventional tillage was done in the experimental plots. Weeds were controlled and irrigation was applied as needed during dry season. Ripened seeds were harvested and measured.

b) Data Collection and Interpretation

- Soil samples were taken at a depth of 0-30 cm for analysis of soil chemical properties. Soil pH was analyzed according to Peech (1965), soil electrical conductivity (EC_e) according to Rhoades (1982), soil organic matter (OM) according to Walkley and Black (1934), available phosphorus according to Bray and Kurtz (1945), extractable potassium according to Chapman (1965) and soluble sodium according to Rhoades (1982).

Figure 4.6 Experimental plot at Suphanburi Agricultural Research and Development Center

Figure 4.7 Land preparation and planting

- Plant growth, height and the diameter of the physic nut crop were recorded from 8 plants per plot every month until 8 months after planting (**Figures 4.8** and **4.9**). Ripened seeds of physic nut were harvested (**Figure 4.10**). The seeds were air dried and then weighted for determination of the yield. The total seed yield each year was determined and 100 seeds were weighed in addition.

Figure 4.8 Measurement of plant height

Figure 4.9 Measurement of diameter

Figure 4.10 Harvest of ripened seeds

- Data of soil samples, plant growth, total seed yield in each year and 100 seed weight were interpreted by analysis of variance under the randomized complete block design.

Statistical analyses were performed using STATISTIX (version 8.0) to determine the effect of different treatments. One way ANOVA (analysis of variance) was used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) was used.

4.3.3 Results and discussion

a) Effect of soil amendments on growth of physic nut

- Plant height: Plant height was recorded once a month until 8 months after planting. The results showed that application of compost at 4 kg plant^{-1} year^{-1} with chemical fertilizer had the highest increased plant height of 96.8 cm at age 8 months (**Figure 4.11**), but it was not significantly different from the other treatments. The treatment of compost at 4 kg plant^{-1} year^{-1}with chemical fertilizer plus bio-extract resulted in the lowest growth rate of 77.7 cm. This result showed no evident effect of organic fertilizer and chemical fertilizer on plant growth.

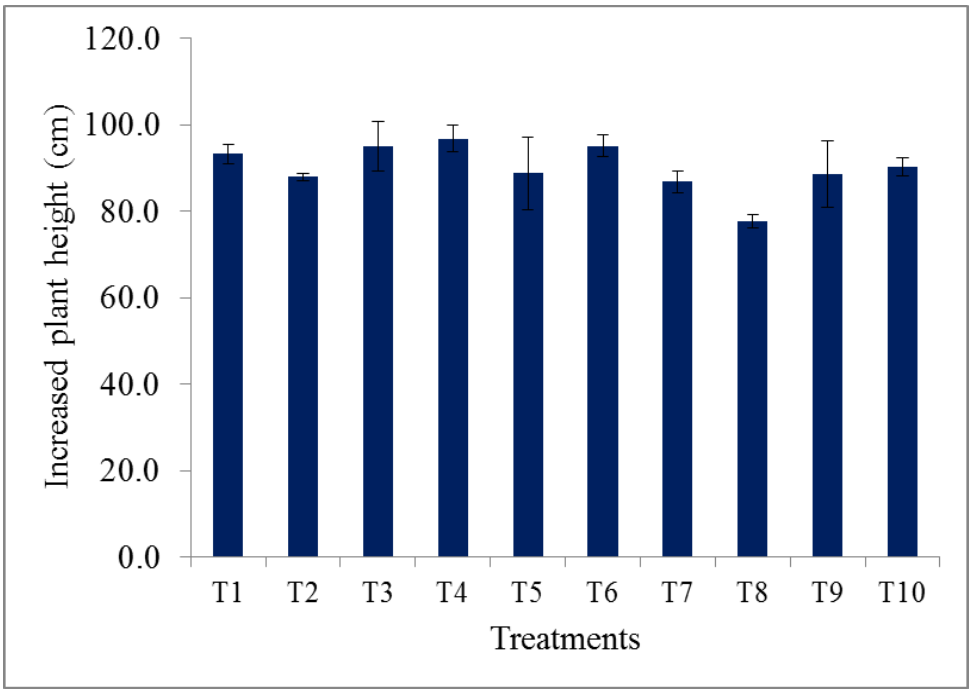


Figure 4.11 Effect of soil amendments on increased plant height of physic nut during 8 months. Bar indicate ± 1standard error of mean. (*Not significant at P< 0.05*)

- **Diameter:** Plant diameter was measured at the same time as plant height. The results showed that the application of compost at 2 kg plant^{-1} year^{-1} with chemical fertilizer plus bio-extract produced the highest change in diameter of 1.0 cm (**Figure 4.12**), which was higher than the application of farmyard manure at 2 kg plant^{-1} year^{-1} with chemical fertilizer (1.0 cm), and of compost at 4 kg plant^{-1} year^{-1} with chemical fertilizer plus bio-extract (0.9 cm), but it was not significantly different. The application of compost at 2 kg plant^{-1} year^{-1} with chemical fertilizer produced the smallest diameter of 0.7 cm.

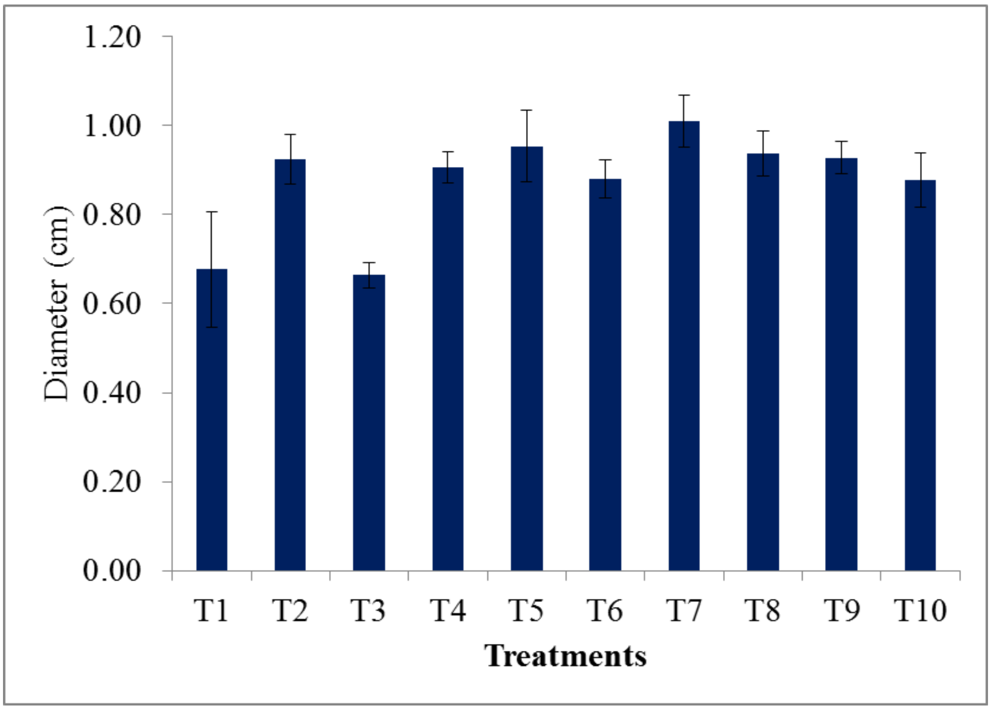


Figure 4.12 Effect of soil amendment on diameter of physic nut during 8 months Bar indicate ± 1standard error of mean. (*Not significant at P< 0.05*)

b) Effect of organic and chemical fertilizer on yields and 100 seeds weight of Physic nut

- **Seed yield:** In the first year (2010), the results showed that the application of compost at 4 kg plant^{-1} year^{-1} with chemical fertilizer resulted in the highest yield of 1.27 t ha^{-1}, which was higher than the application of farmyard manure at 2 kg plant^{-1} year^{-1} with chemical fertilizer plus bio-extract (1.18 t ha^{-1}), and of farmyard manure at 4 kg plant^{-1} year^{-1} with chemical fertilizer (1.17 t ha^{-1}), but it was not significantly different. And the results showed that bio-extract application had no effect on seed yield. The control plot gave the lowest yield of 0.67 t ha^{-1} (**Table 4.17**). In the second year (2011), a similar trend to the first year was found; utilization of organic fertilizer plus chemical fertilizer gave a yield higher only than the chemical fertilizer and control, but not significantly higher. The application of compost at 2 kg $plant^{-1}$ $year^{-1}$with chemical fertilizer plus bio-extract produced the highest yield (1.14 t ha^{-1}), while the control plot had the lowest yield of 0.37 t ha^{-1} (**Table 4.17**). However, in the second year experiment, bio-extract application also had no effect on seed yield.

- Weight of 100 seeds: Seed weight was determined twice in February and December 2010. At the first weighing, the application of compost at 2 kg $plant^{-1}$ $year^{-1}$ with chemical fertilizer tended to give the highest 100-seed weight (63.36 g), while farmyard manure at 4 kg $plant^{-1}$ $year^{-1}$ with chemical fertilizer had the lowest 100-seed weight (40.10 g). In the second weighing, the application of chemical fertilizer tended to produce highest 100-seed weight (60.34 g), while the control plot had the lowest 100-seed weight (20.04 g). The application of chemical fertilizer produced the highest average 100-seed weight of 60.18 g (**Table 4.17**).

c) Change in soil properties

The experiment was conducted in a field experimental plot of the Suphanburi Agricultural Research and Development Center, U-thong district, Suphanburi province. The soils were classified as Kamphaeng Saen soil series (fine-silty, mixed, active, isohyperthermic Typic Haplustalfs).The initial soil properties were determined. Soil pH varied from 6.83 to 7.27. Soil organic matter was in the range 1.57-1.89 %, while the average available phosphorous (P) and potassium (K) were 76.5 and 69.0 mg kg^{-1}, respectively. This soil was slightly saline with an electrical conductivity (EC_e) range of 1.33-2.90 dS m^{-1}. Soluble Na varied from 9.06 to 26.16 m mol l^{-1}.

Table 4.17 Effect of organic and chemical fertilizer on yields (t ha^{-1}) and average 100 seed weight (g) of physic nut.

Treatments	Yields		Average	100 seed weight		Average
	Crop 2010	Crop 2011		Feb 2010	Dec 2010	
1) Control	0.67	0.37	0.52	40.89	20.04	30.47
2) Chemical fertilizer	0.69	0.74	0.71	60.03	60.34	60.19
3) Compost, 2 kg $plant^{-1}$	1.09	0.71	0.90	63.36	48.93	56.15
4) Compost,4 kg $plant^{-1}$	1.27	0.72	0.99	44.91	52.44	48.68
5) FYM, 2 kg $plant^{-1}$	1.06	0.65	0.86	60.48	49.33	54.91
6) FYM, 4 kg $plant^{-1}$	1.17	1.10	1.14	40.10	56.84	48.47
7) Compost, 2 kg $plant^{-1}$+ bio-extract	1.04	0.85	0.95	42.95	54.33	48.64
8) Compost, 4 kg $plant^{-1}$+ bio-extract	1.01	0.58	0.79	49.25	54.03	51.64
9) FYM, 2 kg $plant^{-1}$+ bio-extract	1.18	1.14	1.16	60.74	57.89	59.32
10) FYM, 4 kg $plant^{-1}$+ bio-extract	0.92	0.76	0.84	60.59	48.31	54.45
F-test	ns	ns		ns	ns	
CV (%)	24	73		42	26	

FYM = Farmyard manure; *ns = Not significant at P< 0.05*

The effect of organic fertilizer and chemical fertilizer on changes in the soil properties is shown in **table 4.18.** The application of organic fertilizer with chemical fertilizer resulted in a slight increase in the soil pH. The pH varied from 7.07 to 7.37. No effect of the different application rates of organic fertilizer was found. The soil electrical conductivity (EC_e)

changed slightly after the experiment. No effect of organic fertilizer and chemical fertilizer was found. However there was a soil sampling impact on the EC_e values as the EC_e varied from 0.97 to 2.90 dS m^{-1}. This result conformed with the amount of soluble Na. Generally, soluble Na decreased after the experiment, especially with the application of compost at 4 kg $plant^{-1}$ $year^{-1}$, where the soluble Na decreased from 20.7 to 11.9 m mol l^{-1}.

Table 4.18 Effect of organic and chemical fertilizer on soil properties at 0-30 cm depth.

Treatments	pH		OM (%)		Available P-Bray2 (mg kg^{-1})	
	Before	**After**	**Before**	**After**	**Before**	**After**
T1	7.13	7.27	1.57	1.40	48	170
T2	7.23	7.23	1.68	1.6	47	185
T3	7.00	7.17	1.58	1.43	42	167
T4	7.07	7.10	1.79	1.57	105	203
T5	6.83	7.13	1.72	1.27	88	148
T6	6.93	7.23	1.79	1.63	102	198
T7	7.10	7.17	1.78	1.50	72	179
T8	7.27	7.37	1.60	1.30	89	157
T9	7.17	7.07	1.89	1.53	102	214
T10	7.03	7.23	1.62	1.47	71	191
F-test		ns		ns		ns
C.V. (%)		3.4		9.544		16.7

ns = Not significant at P < 0.05

Table 4.18 (cont.)

Treatment	Extractable K ($mg\ kg^{-1}$)		EC_e ($dS\ m^{-1}$)		Soluble Na^+ ($m\ mol\ l^{-1}$)	
	Before	**After**	**Before**	**After**	**Before**	**After**
T1	63.3	60.7	2.56	1.56	20.5	9.7
T2	75.0	64.7	1.33	0.97	9.1	5.7
T3	78.0	98.7	1.84	1.98	11.4	12.2
T4	62.3	131.0	2.43	1.88	20.7	11.9
T5	64.3	159.3	1.83	2.90	12.0	15.5
T6	71.3	141.3	1.40	1.71	9.4	10.4
T7	70.3	118.7	1.38	1.46	9.4	9.1
T8	64.7	115.0	2.90	2.36	26.2	18.5
T9	70.7	160.0	2.06	2.29	18.3	15.4
T10	69.7	189.7	1.94	2.11	17.4	12.7
F-test		ns		ns		ns
C.V. (%)		59.5		40.1		47.6

ns = Not significant at $P < 0.05$

Organic matter (OM) tended to decrease when compared to initial soil levels. The OM varied from 1.3 to 1.63 %. Utilization of compost at 4 kg $plant^{-1}$ $year^{-1}$ with chemical fertilizer resulted in the highest soil organic matter of 1.63 %. Available P increased after the application of organic fertilizer and chemical fertilizer. The average available P was 181 mg kg^{-1}. Utilization of compost at 2 kg $plant^{-1}$ $year^{-1}$ with chemical fertilizer and bio-extract showed a highest available P level of 214 mg kg^{-1}. Generally, available K increased, except in the control treatment and the treatment with only chemical fertilizer. The application of compost at 4 kg $plant^{-1}$ $year^{-1}$ with chemical fertilizer and bio-extract produced the highest level of available K (190 mg kg^{-1}).

d) Discussion

This experiment was conducted in an experimental field of the Suphanburi Agricultural Research and Development Center, U-thong district, Suphanburi province where the soil was slightly saline. Salinity is an important soil problem for crop production in Thailand as it makes the land unsuitable for agriculture. However, some plants can survive under this condition. Physic nut is one of the species that can adapt to salinity (Gao *et al*., 2008). However, salinity impacted on plant growth and yields. Physic nut showed low average yields of 1.01 and 0.76 t ha^{-1} in the first year and the second year of the experiment. The first year yield was higher because there was a longer harvesting period (12 months) than in the second year (9 months). These results were similar to those of Suriharn *et al*. (2011) who reported low yields of 1.18 and 1.56 t ha^{-1} in the first year and the second year, respectively, while Kumar and Sharma (2008) reported that physic nut had an average annual seed yield range of 2.00-3.00 t ha^{-1} in semi-arid areas. Selection of cuttings was very important in the experiment. This resulted in plants that were better adapted to saline conditions. For the current experiment, cuttings were prepared from physic nut that had been cultivated in a saline area.

Many reports showed that physic nut could adapt and grow under stress conditions with low nutrients; however all crops require nutrients. Thus, in this experiment, treatments 2-10 had applications of chemical fertilizer (15-15-15) at a rate of 156 kg ha^{-1}. In northeastern Thailand, Suriharn *et al*. (2011) recommended to apply chemical fertilizer (15-15-15) at a rate not exceeding 313 kg ha^{-1}. The application of organic and chemical fertilizer in slightly saline soil resulted in increased growth of physic nut but not at a level that was significantly different from the control treatment. This result differed from the research results of Sop *et al*. (2011) who reported that plant growth and biomass development of physic nut were significantly enhanced by organic amendments compared to the control on completely barren and degraded soil. Silpachai *et al*. (2009) reported that the application of organic fertilizer at 4 kg $plant^{-1}$ resulted in a higher growth rate than an application of 2 kg $plant^{-1}$.

For this experiment, application of organic fertilizer had no effect on growth and yield of physic nut. From data of analysis, compost gave low N, P and K content of 2.40, 3.37 and 2.62 %. While farmyard manure also gave low N, P and K content of 1.04, 1.08 and 1.31 %, respectively. These resulted in plant growth. Plant may not get enough N to meet requirement. However, application of organic fertilizer plus chemical fertilizer only tended to increase the seed yield compared to the chemical fertilizer and control, but not to a significant extent. Sukkarin (2008) reported a similar trend, where the application of organic fertilizer plus chemical fertilizer gave a similar yield to the treatment of only chemical fertilizer. Silpachai *et al*. (2009) reported that the application of VA-mycorrhizal fungus with organic fertilizer and phosphorus increased physic nut yields. The current study showed no such effect from organic fertilizer application. For this experiment, bio-extract application also had no effect on seed yield. While Office of Soil Biotechnology (2015) reported that the function of this material are to promote seed germination, root tissue development, stem elongation, stimulate budding, flowering and fruit growth.

The current experiment was conducted in slightly saline soil with low fertility. This area was unsuitable for agriculture. After the experiment, the soil electrical conductivity (EC_e) was slightly changed indicating that there was no apparent effect from the organic fertilizer application. OM tended to decrease when compared to the initial soil analysis. This means that the application of organic fertilizer did not result in increased OM levels. Under saline conditions, OM decomposes easily. The residual effect of the application of organic fertilizer and chemical fertilizer resulted in an increase in the available P and available K. Organic amendment provided nutrients such as C, N, P and K to the degraded soil.

Although growing physic nut under saline conditions will produce lower seed yields, physic nut is believed to have potential in the environmental reclamation of barren areas and degraded soil.

4.3.4 Conclusions

- Application of organic fertilizer plus chemical fertilizer resulted in increased growth of physic nut but not at significantly different levels to the control treatment.

- Application of organic fertilizer had no effect on growth and yield of physic nut, however application of organic fertilizer plus chemical fertilizer only resulted in a higher yield than the application of chemical fertilizer and than the control, but not to a significant degree.

- The soil electrical conductivity changed slightly. The soil organic matter tended to decrease while the available phosphorus tended to increase. Available potassium tended to increase except in the chemical fertilizer treatment and the control treatment.

- Thus it could be recommended that to increase yield of physic nut, N should be considered applying high enough from chemical fertilizer because P and K usually contain high level in soil and from organic fertilizer.

Chapter 5

Usability study results and the participatory approach

Salinity in Northeastern Thailand is an important issue, as this problem affects an area of 1.841 million ha (Office of Soil Survey and Land Use Planning, 2006). Salinity adversely influences plant growth, dramatically decreases yield and degrades agricultural productivity by impeding water uptake, causing an imbalance of plant nutrients and the accumulation of toxic ions (Luttge *et al*., 1984; Sharma, 1984). Numerous studies have indicated that management and remediation of salt-affected soils in Thailand are highly problematic, and approaches depend upon the degree of salinity and location-specific salinization processes. The Land Development Department and involved organizations have tried to solve this problem for a long time, and it can be summarized that there are 3 strategies for management as follows; 1) Agronomic Management, for example, application of organic amendments; land leveling; surface mulching; utilization of salt tolerant varieties; application of green manure, specifically the leguminous *Sesbania rostrata* in slightly to moderately salt-affected lands for rice cultivation. Furthermore, for severely salt-affected soils, halophytes have a role in revegetation of such areas and can contribute to environmental remediation. 2) Biological/Chemical Management, for example, reforestation in the recharge uplands offers an additional approach for salinity control. In addition biological process by using salt tolerant microorganisms can improve and reclaim slightly and moderately saline soil. For chemical management, such as utilization of gypsum or chemical substances, cost should be considered. 3) Engineering Management by leaching and drainage are effective methods in the reclamation of severely saline soils.

From these successful studies on the management of saline soil, the Land Development Department has transferred the appropriate technology to farmers in salinity affected areas. However, these research results are simplified before transferring to farmers. The following are the ways the technology has been transferred to farmers.

5.1 Demonstration plots for increasing rice yield in slightly and moderately saline soil

In general slightly and moderately saline soil is used for rice cultivation. There have been many studies for increased rice yield in these areas. From there research results or technology was transferred to farmers by training and demonstration plots (Arunin, 1984). The technology included leaching and flushing of salt; land leveling; application of organic amendments (such as rice husk; manure, green manure); salt tolerant rice varieties (Khao Dok Mali 105 rice); higher seed rate (6-8 plants per hill); older seedling (30-35 days) and split application of chemical fertilizer (3 times). For examplre, *S. rostrata* was used as green manure in demonstration plot (**Figure 5.1**). The demonstration plots were conducted in farmer fields from 1982 until the present. The example of demonstration plot is shown in **figure 5.2**. The farmers can learn a lot from these technologies and they can adopt them, where suitable, for their own land.

Figure 5.1 Utiliation *Sesbania rostrata* as green manure in demonstration plot

Figure 5.2 Demonstration plot at Khon Kaen province

5.2 Achievement in the utilization of *Sesbania rostrata* as green manure

Numerous studies have indicated that *S. rostrata* shows the highest potential for use as green manure in northeast inland saline soil. The Land Development Department promotes this technology and its officers transfer knowledge to farmers by training and setting demonstration plots (**Figure 5.3**). Every year, seed of *S. rostrata* is distributed to the farmers who have salinity problems in their own land (**Figure 5.4**). Almost all farmers accept this technology because it results in them get higher rice yields after using it. Beside promotion of the use of green manure, the Land Development Department tries to encourage farmers to produce seeds for sale back to the Land Development Department (**Figures 5.5 and 5.6**). It is an alternative means to get more income.

Figure 5.3 Incorporation *S. rostrata* as green manure in demonstration plot

Figure 5.4 Land Development Department supports green manure seed to farmers

Figure 5.5 Land Development Department's staff promotes seed production

Figure 5.6 Seed of *Sesbania rostrata* after harvesting

However, this technology has some problems or disadvantages as follows.

- Low percentage of seed germination rate. It has been found that germination rate drops after one year in storage. Before planting, the seed germination percentage should be tested.

- Variation of amount and distribution of rainfall during planting period. This affects the germination, survival and growth of *Sesbania*. Planting in April without seed treatment is one of the methods used in order to delay germination.

- One of the serious problems is damage to rice seedlings transplanted after incorporation of green manure in to the submerged soil. To avoid this damage, transplanting of rice seedlings is usually delayed for a certain period after incorporation.

- Because *Sesbania* is a fast growing plant, and susceptible to insects, it has been observed that young plants and leaves can be attacked by black aphids. Beetles will attack at the flowering and pod stage, and seeds can be destroyed by a fly.

- The problems of adoption of technology by the farmers include; insufficient quantities of seeds, increased variable costs and labor; problems in cultural practice (since rhizobium inoculation, planting, incorporation and transplanting do not follow established traditions).

5.3 The setting up of the pilot project for integrated management of saline soil

The three methods of saline soil management: Agronomic management, Biological/chemical management and Engineering management have been introduced for the management of saline soil on a large scale at Mueng Pia area, Ban Phai district, Khon Kaen province since 2000. Meung Pia area has a total area of 122,880 ha. Saline soil is found in a large area where it creates a major problem for rice cultivation. This area was identified by the Land Development Regional Office (Khon Kaen), Land Development Department and the project has been carried out by involved organizations. The area was classified based on salinity levels. The saline soil distribution map is used for management planning. The methods of management used depended on the salinity levels also. For engineering management; a drainage system was used for reclamation of severely saline soil (**Figure 5.7**). Land reshaping patterns 1 and 2 were used for rice cultivation in slightly–moderately saline levels (**Figures 5.8 and 5.9**). The characteristics of land reshaping patterns 1 and 2 are shown in **appendix7**. For agronomic management; utilization of salt tolerant plants such as *Acacia ampliceps* (**Figure 5.10**) and *Sporobolus virginicus* (**Figure 5.11**) were planted for rehabilitation of severely saline soil. Utilization of *Sesbania rostrata* (**Figure 5.12**), and the incorporation of rice straw were used for growing salt tolerant rice varieties. Furthermore, Land Development Department promotes to set up farmer groups for production seed of green manure (**Figure 5.13**).

After more than 10 years of implementation, this area has been improved and reclaimed. Farmers get higher rice yields. They get more income and have better livelihoods (Soil and Water Conservation Society of Thailand, 2014).

Figure 5.7 Drainage system for reclamation severely saline soil

Figure 5.8 Land reshape pattern 1 is used for rice cultivation

Figure 5.9 Land reshape pattern 2 is used for rice cultivation

Figure 5.10 *Acacia ampliceps* were planted on rice bund

Figure 5.11 *Sporobolus virginicus* were planted for rehabilitation of severely saline soil

Figure 5.12 To promote utilization of *Sesbania rostrata* as in slightly saline soil

Figure 5.13 To set up farmer groups for production seed of green manure

5.4 Community participatory network

Soil salinity problems cannot be solved by one agency alone. Thus, stakeholder participation in sustainable land management is required. The stakeholders play an important part and can provide many benefits in natural resource management. Reid (2000) summarized community participation as one of the key factors that empowered community success. Research results or technology compiled with community wisdom is an alternative for salinity management. So in the year 2011, the Land Development Department established the project on "Setting up Community Participatory Network for the Best Practices of Saline Soil Management in Northeastern Thailand". The objective of the current project was to initiate a community participatory network to address the problem of salinity management and to prevent saline soil distribution in Northeastern Thailand. The results were reported by Pongwichian *et al.* (2012). The project was carried out in pilot areas in Nakon Ratchasima and Khon Kaen provinces because both provinces have large areas of saline soil, (0.616 and 0.329 million ha, respectively). From the first meeting, stakeholders from 2 provinces created two action plans, one at the community and the other at the household level (**Tables 5.1 and 5.2**). **Figures 5.14 and 5.15** show activities during the meeting; stakeholders were divided into small group for brainstorming and group leaders presented the best management practices of action plan after brainstorming.

Table 5.1 Action plan for saline soil management at the community level.

Activities	Process
1. To better understand saline soil management.	1. Setting up meetings for better understanding of all landholders, coordinating with related organizations.
2. To reshape the land.	2. Setting up meetings for better understanding of all landholders, coordinating with related organizations.
3. To set up the compost and bio-extract user groups.	3. Gathering together all farmers that produce and use compost and bio-extracts for group setting and learning from the achievements of the community.
4. To set up the Khao Dok Mali 105 rice producer group.	4. Gathering together all farmers that produce Khao Dok Mali 105 rice for group setting. Ensure appropriate cultivation is used such as suitable land preparation and using pure seed.
5. To promote reforestation.	5. Growing community forests and reforestation on levees for preservation of soil moisture content, mitigation of global warming, growing firewood and controlling the groundwater level.
6. To set up farmer groups for planting vetiver grass.	6. Gathering all farmers that plant vetiver grass for group setting and promoting planting of vetiver grass in agricultural areas and along the banks of ponds or reservoirs.

Table 5.2 Action plan for saline soil management at the household level.

Activities	Process
1. To reclaim land by using organic fertilizer.	1. Organic amendments such as farmyard manure, compost, green manure, rice husk and incorporation of stubble will be used for agricultural production.
2. To reshape the land.	2. Leveling the land, constructing drainage systems and farm roads, growing perennial trees on levees.
3. To grow salt tolerant crops.	3. Selection of salt tolerant crops for planting in saline soil such as Khao Dok Mali 105 rice and *Sesbania rostrata* for use as green manure
4. To look for alternative land uses.	4. For severely saline soil where cash crops cannot grow, land use should be changed to aquaculture.
5. To plant alternative crops after rice.	5. Growing vegetable crops such as lettuce, parsley and shallot.
6. To provide water resources for agriculture.	6. The leader of the community contacts the Land Development Department to gain access to water resources for the community.

Figure 5.14 Stakeholders were divided into small group for brainstorming

Figure 5.15 Group leaders presented the best management practices of action plan

The next step was to determine the best practices. Two effective communities at Khamthaleso district, NakonRatchasima province were selected. At the workshop, officers provided information on land resources (**Figure 5.16**). And then the stakeholders brainstormed to identify the best practices (**Figure 5.17**). The approaches were based on the degree of salinity and location-specific salinization processes. The results from the two workshops indicated that sustainable land management depended upon the salinity level, location, socio-economic factors and public agreement. (**Tables 5.3 and 5.4**).

Table 5.3 Best practices for sustainable salinity management at Ban Nongsuang.

Slightly saline soil	Moderately saline soil	Severely saline soil
1. To reclaim land by using organic fertilizer. 2. To provide water resource. 3. To reshape the land. 4. To produce Khao Dok Mali 105 rice variety. 5. To grow salt tolerant cash crops. 6. To select salt tolerant trees for growing.	1. To set up a meeting for better understanding of the salinity problem and its management. 2.To reclaim land by using organic fertilizer. 3.To reshape the land and make drainage system. 4. To provide water resource. 5. To select salt tolerant trees for growing.	1. To set up a meeting for better understanding of the salinity problem and its management. 2. To reshape the land. 3. To reclaim land by using organic fertilizer and gypsum. 4. To select salt tolerant trees for growing.

Table 5.4 Best practices for sustainable salinity management at Ban Pandung.

Moderately saline soil	Severely saline soil
1. To set up a meeting for better understanding of the salinity problem and its management. 2. To reclaim land by using organic fertilizer. 3. To reshape the land. 4. To provide water resource 5. To grow salt tolerant trees	1. To set up a meeting for better understanding of the salinity problem and its management. 2. To reshape the land. 3. To reclaim land by using organic fertilizer. 4. To look for alternative land use.

Figure 5.16 Officers providing information on land resources

Figure 5.17 Stakeholders brainstormed to find out the best practice

A community participatory network is an appropriate approach to not only fulfilling the goals but also solving the salinity problem. Furthermore, this concept or model can be adopted and used for the management of salinity problems and the prevention of the soil salinity in any location. In addition to salinity, this model for management can be adopted to address other agricultural problems.

5.5 Volunteer soil doctor; A network for soils resource management

Up to the present, the use of unsuitable land for agriculture has been problematic with land degradation impacting on the farmer's living. Land degradation has been the cause of low yields and also impacting on the farmer's income. The problems of land are not only erosion and soil organic matter deficiency, but also saline soil, acid soil, organic soil and sandy soil. And the mission of the Land Development Department is to develop basic infrastructure for land development, soil improvement and soil rehabilitation to increase agricultural productivity and sustainable land use. The Land Development Department has a staff of only 3,550 people and this is not enough to carry out these missions in the whole of Thailand for example, implementing soil management and improvement. It is necessary for the farmers and people to participate and work together to take care of natural resources. The Ministry of Agriculture and Cooperatives has policy guidelines to build up volunteers who will disseminate land development plans in the villages called "volunteer soil doctors" (Land Development Department, 2015). The official logo of volunteer soil doctors is shown as **figure 5.18**.

Figure 5.18 Official logo of volunteer soil doctors

Soil doctor volunteers have been assigned to carry out soil management in each village since 1995. They are advanced farmers acting as representatives of, and collaborators between, farmers and the Land Development Department's staff for conservation of natural resources, especially soil resources. Firstly, they will get general training to be aware of the importance of soil resources (**Figure 5.19**). After training, they are perfect volunteer soil doctor (**Figure 5.20**). At present, there are more than 80,000 soil doctor volunteers. Soil doctor volunteers should be in good health, eligible(at least 18 years old), willing to work, keen on land development activities, residing in the areas concerned and have their spouse consent to be a Volunteer Soil Doctor. Basically, Volunteer Soil Doctors cooperate in assisting farmers to obtain better understanding and practice of soil conservation and sustainable land resources management. Volunteer Soil Doctors will be fully supported with tools, maps and manuals which the Land Development Department provides to help them perform their task effectively. Sub - district's Technology Transfer and Learning Center is established (**Figure 5.21**). This center normally used for distribution some agricultural materials such as vetiver grass, green manure seeds and lime to farmers (**Figure 5.22**). They have to cooperate between farmers and the Land Development Department, to demonstrate appropriate technologies to the neighborhood committees and to have activities with the Land Development Department, for example - to conduct demonstration plots for vetiver propagation (**Figure 5.23**), to create and help groups of farmers using organic fertilizer, to set up demonstration plots and to transfer suitable technology (**Figures 5.24, 5.25 and 5.26**).

Figure 5.19 General training to be aware of the importance of soil resources

Figure 5.20 After training, they are perfect volunteer soil doctor

Figure 5.21 Sub - district's Technology Transfer and Learning Center

(a) (b) (c)

Figure 5.22 Distribution some agricultural materials such as (a) Vetiver grass, (b) Green manure seeds and (c) Lime to farmers

Figure 5.23 Vetiver grass demonstration plot

Figure 5.24 Transfer technology to farmers to produce compost

Figure 5.25 Transfer technology to students

Figure 5.26 Transfer technology to farmers to produce bio-extract

The Land Development Department has established a network of volunteer soil doctors projects, in order to increase the efficiency of volunteer soil doctors and to support the Land Development Department activity and government. The Land Development Department improved and updated personal data in a digital system in order to establish soil doctors networks at the Tambon level of local government, to support the policy of Ministry of Agriculture and Cooperative and also to develop the network know-how of volunteer soil doctors in many areas.

Chapter 6

Summary

6.1 Introduction

The soil resource of Thailand differs in thickness, texture, drainage capacity, fertility, degree of flooding and in many other ways. There are many problems such as salt affected soil, acid sulfate soil, sandy soil, shallow and acid soil, and a mountainous area which covers an area of 43.3 million hectares. These problem soils affect plant growth. Among the problem soils, saline soil is one of main agricultural problem soils. In Thailand, saline soils cover an area of 2.302 million ha. About 1.841 million ha is found in the northeastern part, whereas other areas of 0.425 million ha and 0.063 million ha are coastal saline soil and soils in other regions, respectively. The management of saline soils is often problematic. Management and remediation of salt-affected soils depends upon the degree of salinity and the specific salinization processes, through approaches of agronomic management, biological/chemical management and engineering management.

For agronomic management, present recommended strategies include leaching, land leveling, surface mulching, application of organic amendments, deep plowing and the utilization of salt tolerant varieties. For slightly to moderately salt-affected lands used for rice cultivation, the application of green manure, specifically the leguminous *Sesbania rostrata* has been identified as having active potential for rain fed lowland rice systems. For severely salt-affected soils, halophytes have a role in revegetation of such areas and can contribute to environmental remediation. Biological processes used by salt tolerant microorganisms can improve and reclaim slightly and moderately saline soil. However, studies on halophilic bacteria in Thailand are limited and this method is not practical for farmers. In addition, reforestation of the upland recharge areas offers another approach for salinity control. But it requires high investment and the system is generally only feasible as a large-scale government initiative. For chemical management such as utilization of gypsum or other chemical substances, cost should be considered as the chemicals are expensive. Engineering management, through leaching and drainage, is an effective method for the reclamation of severely saline soils. This technique requires high investment and the system is generally only feasible as a large-scale government initiative, as the farmers or land owners cannot do it by themselves. From the perspectives of cost-performance, natural environment and the country's farmers' capacity, Agronomic Management serves as the best method for Thailand. The best form of management must be site specific.

The objectives of this dissertation are to establish site-specific methods of using appropriate agronomic management with different salt tolerant species in the saline soils of Thailand and to determine the soil productivity while using the appropriate agronomic management with different salt tolerant species in saline soil of Thailand. The originality of this research was to figure out the best agronomic management (site-specific) in all types of saline soils (lowland) in Thailand.

6.2 Methodology

The dissertation on **"Agronomic Management of Saline Soil in Agricultural Lands of Thailand"** has been studied and compiled in the years 1993-2015. The study areas are all types of saline soil in Thailand. For inland saline, the experiments were conducted in the northeastern part of Thailand while the experiment on coastal saline soil was carried out in Petchaburi province. For the central plain saline soil, the experiments were conducted in the central part of Thailand. All areas are lowlands. For plant types, salt-tolerant species of Paddy, Broccoli, Sugarcane, Physic nut, *Sesbania* spp. and Halophytes (4 species) were tested in the farmers' fields. Measured parameters, data of plant growths and yields were collected, while soil samples after experiments were analyzed for soil properties such as pH, EC_e, OM, available nutrients (N, P, K) and Na. Statistical analyses were performed using IRRISTAT and STATISTIX (version 8.0) to determine the effect of different treatments.

One way and two way ANOVA (analysis of variance) were used to investigate the level of significance ($P<0.01$, 0.05). To compare the means, Duncan's Multiple Range Test (DMRT) and LSD (Least Significant Difference) were used.

6.3 Appropriate agronomic management

6.3.1 Inland saline soil: Empirical studies of the utilization of green manure in saline soil are outlined below.

Green manure is suitable for managing salt-affected soils as a source of plant nutrients and a supply of energy to soil microorganisms. Numerous studies indicate that *Sesbania rostrata* L., a stem-nodulating legume shows high potential as a green manure crop in salt-affected soils for rainfed lowland rice systems. *S. rostrata* is originally from South Africa, and has been studied as a green manure for rice in many countries, including in the saline soils of Thailand. The following are some studies.

a) The first study was the "**Effects of *Sesbania rostrata* on two rice planting methods in saline soils**". Two rice varieties of RD 15 and KDML 105were planted by transplanting and dry seeded methods with and without *S. rostrata* plantation. The results showed that utilization of *S. rostrata* showed higher rice yields with both the dry seeded method and the transplanting method.

b) The second study was the **"Optimum incorporation age of *Sesbania rostrata* as green manure for rice in saline soil"**. The experimental design was randomized complete block (RCBD). Incorporation age of 40, 45, 50, 55, 60 and 65 days after sowing (das) were studied. Data of growth and N-accumulation of *Sesbania* were collected and data of yield were recorded also. The effect of incorporation of *S. rostrata* on the change of soil properties was studied. The results showed that biomass and N accumulation of *Sesbania* increased with increasing age. Utilization of *Sesbania* at age of 65 das gave highest average rice yield.

c) The third study was the **"Effect of soil amendment and rice cultivation on salt movement in the open ditch system of severely saline soil".** The study was carried out in severely saline soil. The use of compost, farmyard manure, rice husk and *S. rostrata* was studied under randomized complete block design. For the three years of the experiment, it was found that application of farmyard manure gave the highest rice yields while use of *S. rostrata* also showed high rice yield. So *S. rostrata* had an almost similar salinity-mitigation effect compared to the other soil amendments.

It can be summarized that *S. rostrata,* if used as a green manure, has high potential to mitigate salinity on inland salt-affected soils under rain fed lowland rice systems. Application of *S. rostrata* (green manure) increased rice yields by up to 30 % while soil electrical conductivity decreased.

6.3.2 Coastal saline soil

The study on "**Utilization of salt tolerant species for rehabilitation of coastal saline soil in Petchaburi province Thailand"** was undertaken at the Sirindhorn International Environmental Park, Cha-am district, Petchaburi province. The objectives of our research were to compare the growth of different halophytes in saline soils in coastal areas and to investigate the effect of halophytes on changes in soils properties and their suitability for the rehabilitation of coastal saline soils. Four species of halophytes namely, Dixie grass (*Sporobolus virginicus*, coarse type), Smyrna grass (*Sporobolus virginicus*, smooth type), Seabrook grass (*Distichlis spicata*) and Georgia grass (*Spartina patens*) were studied. The results showed that Seabrook grass gave the highest fresh and dry weights. After plantation of all species, it found that soil electrical conductivity and soluble sodium were decreased. Seabrook grass in particular could grow under a higher level of salinity and showed higher soil organic matter and available Phosphorus after plantation.

For this soil, it could be summarized that Seabrook grass had the highest growth, highest fresh and dry weights, and the best nutrient accumulation, especially of nitrogen and sodium. Growing Seabrook grass is recommended in severely saline coastal soil.

6.3.3 Central plain saline soil

In this area, rice and sugarcane cultivation are common, although yields are generally low. A number of farmers have changed from rice and sugarcane to higher income cash crops. Numerous studies have indicated that selection of salt-tolerant varieties, mulching to conserve soil moisture, application of organic amendments (green manure, compost, farmyard manure) for improved soil fertility, and drip irrigation for increasing the efficiency of irrigation, could increase crop yields. For example, in the study on **"Effect of planting methods, mulching and seedling age on yields of broccoli in central plain Saline Soil"**, the results showed that the mound planting method with seedlings age 25 days gave highest yields of Broccoli in the first year. In the second year; for the flat planting method, mulching had no effect, but mulching showed higher yields in the mound planting method. Besides the study on vegetables, the study on **"Effects of soil amendments on yield of sugarcane"** was studied. It found that farmyard manure (FYM) worked better compared to other treatments and resulted in higher sugarcane yields. Soil amendments resulted in higher levels of soil OM, available phosphorus and potassium. Soil electrical conductivity (EC_e) tended to decrease.

The study on "**Effect of organic and chemical fertilizer on growth and yield of Physic Nut (*Jatropha curcas* L.) in slightly saline soil"** was conducted to find out the appropriate management of slightly saline soil in the central plain of Thailand to increase physic nut yield and to study the effect of soil amendments on changes in the soil chemical properties. It found that application of organic fertilizer plus chemical fertilizer resulted in a higher yield than the application of only chemical fertilizer. Application of farmyard manure at 4 kg $plant^{-1}$ per year was recommended.

6.4. Conclusions

In inland saline soil, if used as a green manure, *Sesbania rostrata* has high potential to mitigate soil salinity in agricultural lands. For coastal saline soil, environmental rehabilitation by salt tolerant halophytic grasses, such as Seabrook grass, is recommended in severely saline soils. For central plain saline soil, cash crops such as Broccoli, Sugarcane and Physic nuts grow well with organic and chemical fertilizer in slightly and moderately saline soil.

Therefore, site-specific agronomic methods to mitigate soil-salinity are quite feasible and more environmentally-friendly compared to other methods (chemical or engineering methods) in Thailand. These technologies are being transferred to the farmers.

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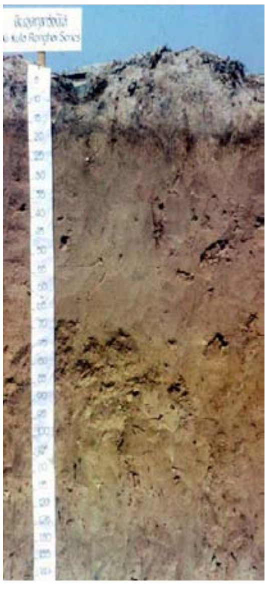
Appendix

Appendix1. The example of soil series found in saline soil

Appendix1.1 Soil series found in inland saline soil

Roi-Et series
(Re-sa)



Kula Ronghai series
(Ki)

Udon series
(Ud)

Appendix1.2 Soil series found in coastal saline soil

Samut Prakan series

Bang Pakong series

Tha Chin series

(Sm) **(Bpg)** **(Tc)**

Appendix1.3 Soil series found in central plain saline soil

Kamphaeng Saen Series
(Ks)

Appendix2. Relative salt tolerances of plants at different salinity levels (Arunin, 1996).

Slightly saline soils	**Moderately saline soils**	**Severely salt-affected soils**		
		Slightly	**Moderately**	**Very highly**
2-4	**4-8**	**8-12**	**12-16**	**>16**
		Vegetables		
Yard long bean (*Vigna unguiculata*)	Onion (*Allium cepa*)	Chinese spinach (*Amaranthus lividus* L.)	Asparagus (*Asparagus officinalis*)	
Chinese Cabbage (*Brassica pekinensis)*	Sweet corn (*Zea mays accharata*)	Chinese radish (*Raphanus sativus)*	Chinese Kale (*Brassica alboglabra*)	
Celery (*Aqium graveolens*)	Cabbage (*Brassica oleracea)*	Tomato (*Solanum lycopersicum*)	Holy basil (*Ocimum sanctum)*	
Cucumber (*Cucumis sativus)*	Potato (*Solanum tuberosum)*	Cowpea (*Vigna unguiculata*)	Water convolvulus (*Ipomoea aquatic*)	
Melon (*Cucumis melo)*	Watermelon (*Citrullus lanatus)*	Climbing wattle (*Senegalia pennata*)		
	Cantaloupe (*Cucumis melo*)			
		Flowers		
Gerbera (*Gerbera jamesonii*)	Rose (*Rosa hybrid*)	Everlasting (*Gomphrena globosa*)	Purslane (*Portulaca oleracea*)	
		Bougainvillea (*Bougainvillea hybrid*)	West Indian Jasmine (*Ixora chinensis* Lamk.*)*	

Field crops and forage				
Mung been (*Vigna radiate*)	Rice *(Oryza sativa*)	Salt-tolerant rice *(Oryza sativa*)	Cotton *(Gossypium hirsutum* L.)	Dixie (*Sporrobolus virginicus*)
Soybean *(Glycine max*)	Sorghum *(Sorghum bicolor*)	Safflower *(Carthamus tinctorius*)	Burmuda grass *(Cynodon dactylon*)	Smyrna (*S. virginicus*)
Peanut *(Arachis spp.*)	Corn *(Zea mays*)	*Sesbania rostrata*	Napier grass *(Pennisetum purpureum*)	Georgia (*Spartina patens*)
Sesame *(Sesamum indicum*)	Cassava *(Manihot esculenta*)	Sweet Potato *(Ipomoea batatas*)		Seabrook (*Distichlis spicata)*
Trees and fruit trees				
Banana *(Musa sapientum* L.)	Pomegranate *(Punica granatum*)	Black wattle *(Acacia auriculiformis*)	Sapodilla *(Manilkara zapota*)	*Acacia ampliceps*
Lychee *(Litchi chinensis*)	Oil palm *(Elaeis guineensis* Jacq.)	Guava *(Psidium guajava*)	Jujube *(Zizyphus mauritiana* Lam*)*	*Casuarina glauca*
Lime *(Citrus aurantifolia*)	Rose apple *(Syzygium jambos*)	*Eucalyptus camaldulensis*	Tamarind (*Tamarindus indica*)	*Melaleuca acaciodes*
Orange *(Citrus reticulate*)		Manila Tamarind *(Pithecellobium dulce*)	Coconut *(Cocos nucifera*)	Tall-Stilt Mangrove *(Rhizophora apiculata*)
Mango *(Mangifera indica*)			Date Palm *(Phoenix dactylifera* L.)	Red Mangrove *(Rhizophora mucronata*)
			Neem tree *(Azadirachta indica*)	

Appendix3. Suitable placement of seed in saline soil.

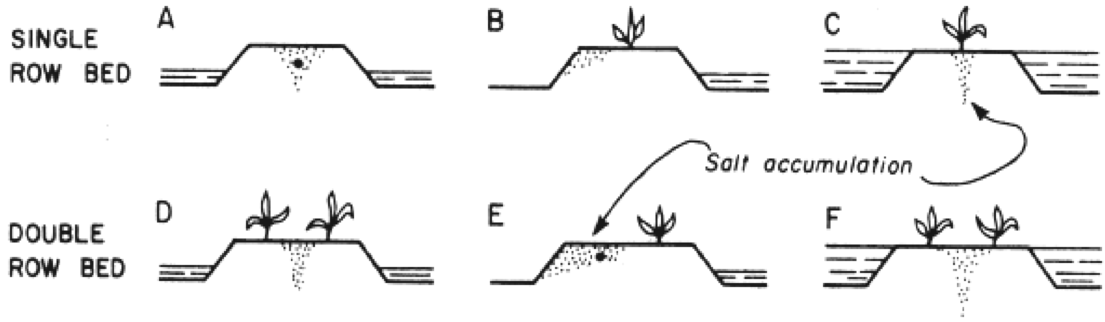


Figure Appendix3-1 Flat top beds and irrigation practice (Bernstein, Fireman and Reeve 1975)

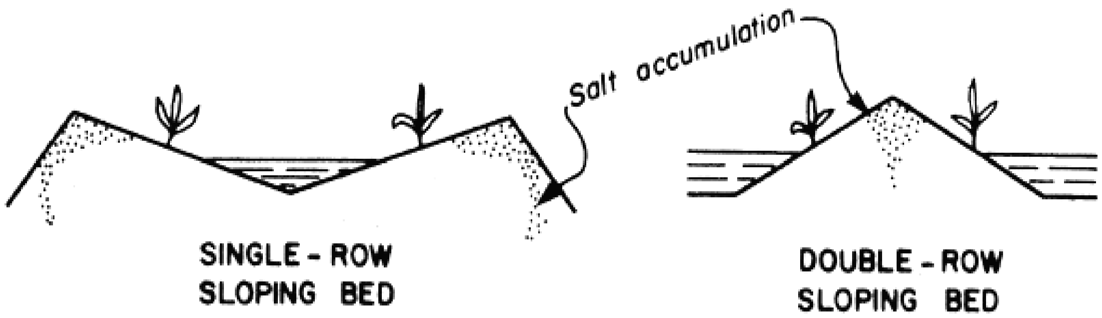


Figure Appendix3-2 Salinity control with sloping beds (Bernstein and Fireman 1957)

Figure Appendix3-3 Sloping seedbeds used for salinity and temperature control

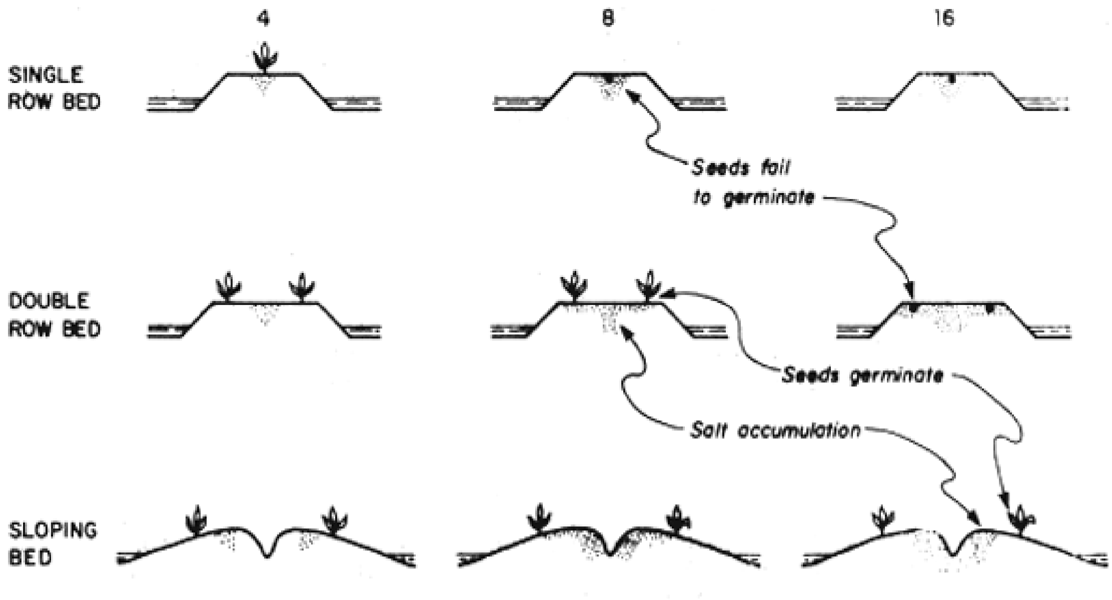


Figure Appendix3-4 Bed shapes and salinity effects (Bernstein, Fireman and Reeve 1955)

Appendix4. Fast growing tree species recommended for reduction ground water in northeast Thailand.

Non saline soil (recharge area) (EC_e 0.2-2 dS m^{-1})	**Slightly-moderately saline soil (EC_e 2-12 dS m^{-1})**	**Severely saline soil (discharge area) (EC_e 12-45 dS m^{-1})**
Exotic species	**Exotic species**	**Exotic species**
Acacia auriculiformis	*Acacia salicina*	*Acacia ampliceps*
Acacia mangium	*Eucalyptus camaldulensis*	*Casuarina glauca*
Eucalyptus tereticornis	*Eucalyptus tereticornis*	*Melaleuca acacioides*
Eucalyptus camaldulensis		*Melaleuca leucadendra*
Casuarina equisetifalia		
Local species	**Local species**	**Local species**
Leucaena leucocephala	*Melaleuca leucadendra*	*Combretum adrangulare*
Cassia siamea	*Melia azedarach*	*Tamarindus indica*
Sesbania grandiflora	*Azadirachta indica*	*Pithecellobium dulce*
Azadirachta excelsa	*Acacia catechu*	*Zizyphus mauritiana*

Source: Dissataporn *et al.* (1992)

Appendix5. Effect of reforestation on levels and salinity of groundwater in the recharge and discharge area

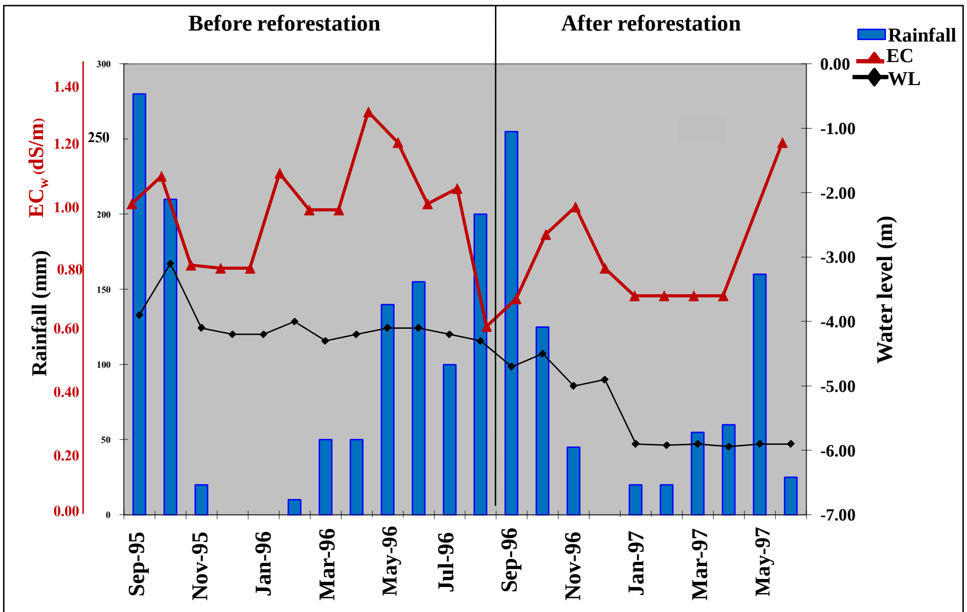


Figure Appendix6.1 Groundwater level (WL) and electrical conductivity (EC_w) measured from piezometers in the recharge area.

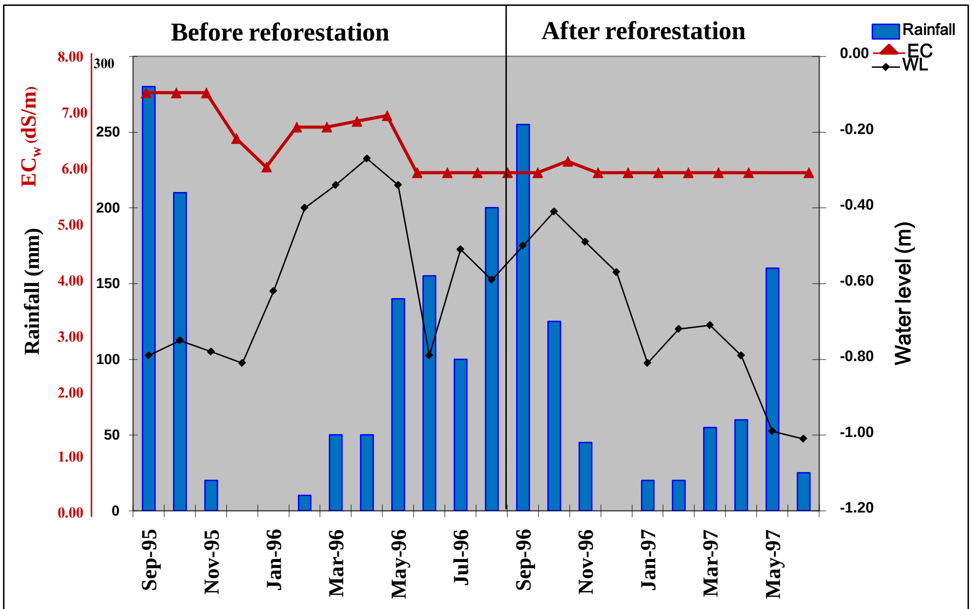


Figure Appendix6.2 Groundwater level (WL) and electrical conductivity (EC_w) measured from piezometers in the discharge area.

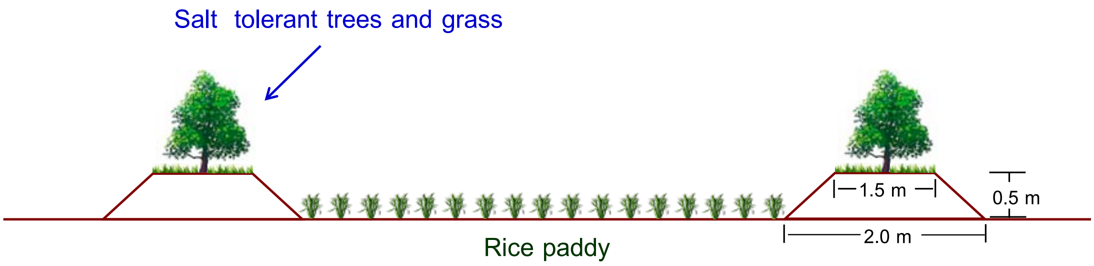
Appendix6. Nutrients content of green manure

Green Manure	Nutrient content (%)		
	Nitrogen	**Phosphorus**	**Potassium**
Crotalaria juncea	2.19-4.38	0.15-0.52	1.54-2.14
Vigna unguiculata	2.21-3.31	0.31-0.43	2.31-3.57
Canavalia ensiformis	2.03-3.13	0.41-0.49	0.81-1.23
Cajanus cajan	1.64-3.28	0.10-0.36	0.89-2.94
Sesbania rostrata	1.55-3.51	0.21-0.69	1.59-1.93
Sesbania aculeata	2.72	0.44	1.83
Sesbania speciosa	3.44	0.56	2.62
Sesbania cannabina	3.15	0.47	1.98

Source: Land Development Department (2015)

Appendix7. Two land reshaping patterns in the paddy field

7.1 Land reshaping pattern 1: To level the land and adjust the ridge height of 0.5 meters and wide of 1.5 meters. Salt tolerant trees such as *Acacia ampliceps*, *Azadirachta indica* and eucalyptus are planted on the ridge. When the rains fallen that water trapped to wash the salt down vertically in the paddy soil.



7.2) Land reshaping pattern 2: To level the land and make drainage system for controlling groundwater levels. Salt tolerant trees such as *Acacia ampliceps*, *Azadirachta indica* and eucalyptus are planted on the ridge**.**