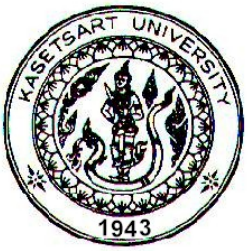

THESIS

DECISION SUPPORT SYSTEM FOR EUCALYPT PLANTATION INVESTMENT IN CHACHOENGSAO PROVINCE

PIYAWAT DILOKSUMPUN

GRADUATE SCHOOL, KASETSART UNIVERSITY

2008

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THESIS

DECISION SUPPORT SYSTEM FOR EUCALYPT PLANTATION INVESTMENT IN CHACHOENGSAO PROVINCE

PIYAWAT DILOKSUMPUN

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy (Forestry)
Graduate School, Kasetsart University
2008

Piyawat Diloksumpun 2008: Decision Support System for Eucalypt Plantation Investment in Chachoengsao Province. Doctor of Philosophy (Forestry), Major Field: Forestry, Interdisciplinary Graduate Program. Thesis Advisor: Assistant Professor Wanchai Arunpraparut, D.Agr. 198 pages.

The main objective of the study was to develop an integrated decision support system (DSS) for eucalypt plantation investment in Chachoengsao province that could be able to determine site suitability, plantation yield, financial returns, and appropriate plantation management.

The DSS development in the present study can be separated into four main parts, namely database design and analysis, DSS procedure, user interface design, and system output. Firstly, a system database was designed and developed to provide critical requirements for decision-making based on the DSS objectives. Secondly, decision hierarchy was constructed to clarify the choice situation of lands accordingly. Based on the 3-year-old eucalypt production, site suitability was categorized into four classes, i.e. very good site quality, good site quality, moderate site quality, and unsuitable site. Eucalypt production was then predicted by respective growth model to provide information for financial analysis procedure. Thirdly, management system of the user interface was designed according to the user-friendly interactive concept for simplicity and high information content. The welcome homepage, input data pages, interactive pages, and output pages were specially designed to communicate with users gradually. Lastly, various report output pages were designed to provide all conclusive information needed for decision-making of eucalypt plantation investment.

Furthermore, the DSS developed in the present study was designed to be flexible and able to update some system database for future uses and development. Development of a growth model that integrated site potential, climatic data, and physiological characteristics, as well as management practices is, therefore, essential to improve the accuracy and reliability of the growth/yield prediction in decision-making.

Piyawat Diloksumpun — Student's signature

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2 / 6 / 2008

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Piyawat Diloksumpun
28 May 2008

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LIST OF ABBREVIATIONS

AC-pd	=	Alluvial soils, poorly drained complex
AC-wd	=	Alluvial soils well drained complex
AI	=	Artificial intelligent
B/C ratio	=	benefit-cost ratio
Bbg	=	Ban Bueng series
Bk	=	Bangkok series
Bka	=	Bang Khla series
Bka&Bka-br	=	Bang Khla and Bang Khla, brown soils
Bka-br	=	Bang Khla, brown variant
Bp	=	Bang Nam Priao series
Bpg	=	Bang Pakong series
Ca	=	Cha-am series
Cb	=	Chon Buri series
Cc	=	Chachoengsao series
Cm	=	centimeter
DBH	=	diameter at breast height
Dm	=	Don Mueang series
Dr	=	Don Rai series
Dr&Kt	=	Don Rai and Korat soils
DSS	=	Decision support system
ER	=	entity relation
FAO	=	Food and Agriculture Organization
Fsh	=	Fish and Shrimp ponds - and Salt pans
GIS	=	Geographic information system
GPS	=	Global positioning system
H	=	total height
Ha	=	Hectare
Hg	=	Hup Kapong series

LIST OF ABBREVIATIONS (Continued)

Hg&Sh	=	Hup Kapong and Sattahip soil
Hk	=	Hin Kong series
Hk/Kkn	=	Hin Kong/Ko Khanun association
Kb	=	Kabin Buri series
Kb&Kb-br	=	Kabin Buri and Kabin Buri, brown soils
Kb&Kb-br&Kb-l	=	Kabin Buri and Kabin Buri, brown variant and Kabin Buri, loamy variant soils
Kb-br	=	Kabin Buri, brown variant
Kkn	=	Ko Khanun series
Kl	=	Klaeng series
Kl-ow	=	Klaeng, overwash phase
Kt	=	Korat series
LDD	=	Land Development Department
Ly/Ty	=	Lat Ya/Tha Yang association
Ma	=	Maha Pho series
MAI	=	Mean annual increment
Mb	=	Map Bon series
Mb-c	=	Map Bon, clayey variant
mm	=	millimeter
NBC	=	Undifferentiated ridged acid soils
Nkk	=	Nong Khok series
NPV	=	Net Present Value
Ok	=	Ongkharak series
Pg	=	Pang Rai series
Pg&Suk-md	=	Pang Rai and Satuk, moderate soils
Pn	=	Phen series
Ptg	=	Phan Thong series
RFD	=	Royal Forest Department
Rs	=	Rangsit series

LIST OF ABBREVIATIONS (Continued)

Rs-a	=	Rangsit, very acid phase
Sc	=	Slope Complex
Sh	=	Sattahip series
Sh-gr	=	Sattahip, gravelly variant
Sk	=	Sakon series
Sk&Bka&Pp	=	Sakon and Bang Khla and Phon Phisai soils
Suk	=	Satuk series
Suk&Wn	=	Satuk and Warin soils
Suk-col	=	Satuk, coarse loamy variant
Suk-gra	=	Satuk, granite derived variant
Suk-md	=	Satuk, moderately deep variant
Tc&Bpg	=	Tha Chin and Bang Pakong series
Ty	=	Tha Yang series
UMN	=	University of Minnesota
USDA	=	United State Department of Agriculture
W	=	Water boundaries i.e. river, canal, lake or pond, intermittent pond and wet spot
W_b	=	branch biomass
W_{fs}	=	economic production or stem fresh weight
W_l	=	leaf biomass
Wn	=	Warin series
W_s	=	stem biomass

DECISION SUPPORT SYSTEM FOR EUCALYPT PLANTATION INVESTMENT IN CHACHOENGSAO PROVINCE

INTRODUCTION

A rapid expansion of major wood-based industries, including pulp mills, chip mills and medium-density fiberboard (MDF) plants, has led to the acute demand for eucalypt wood in Thailand (Luangviriyasaeng, 2003). Consequently, commercial eucalypt plantations, playing an outstanding role in woodchip and short-fiber wood pulp industries, have been expanded extensively in both government and private sectors. The current production capacity based on the total plantation area of about 500,000 ha seems sufficient to meet the domestic demand at least the immediate future. Nevertheless, Thailand has been facing eucalypt timber shortage. Although eucalypts are fast and easy growing species with low mortality rates, plantation entrepreneurs have also realized the extremely high variations in their growth and yield as the results of planting genetic materials, site conditions and environments, and silviculture and management practices (Luangviriyasaeng, 2003; Thaitusa *et al*., 2004). Moreover, the major sources of raw material seem rather too far to be profitably transported to woodchip factories (Thaitusa *et al*., 2004). Costs of plantation establishment and management as well as transportation must be, therefore, taken into consideration prior to the investment of commercial plantations. These factors lead to complicated decision-making to fulfill the demand for eucalypt wood and to maximize profits of the investment.

Decision support system (DSS) is an interactive computer-based information system, which helps decision makers to utilize data and models in order to solve unstructured management problems for improved decision-making (Turban and Aronson, 2000). It basically utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights. Applications of DSS for forest management are considered valuable since the requirements defined are extremely high due to the complexity, the uncertainty, and the enormous amount of data. For

instance, a conceptual framework of a DSS for management of lowland pine forest described by Kaloudis *et al*. (2001) has been useful for reduction of wildfire damage. In commercial plantation management, many support tools are also available in practices, e.g. potential of planting site, soil mapping, growth model, benefit-cost analysis, but these have not yet been brought together into an integrated system. The development of DSS for eucalypt plantation in Chachoengsao province, where major woodchip and pulp industries have been located, is an attempt to use another means to integrate the required data and make them more readily available for decision makers prior to the investments.

OBJECTIVES

The main objective of the study was to develop an integrated DSS for eucalypt plantation investment in Chachoengsao province with the following specific focuses:

1. To determine the site suitability for eucalypt planting;
2. To estimate growth and yield of eucalypt plantations in each site quality;
3. To estimate financial returns for investment of eucalypt plantation in each site quality; and
4. To recommend appropriate practices and management for investment of eucalypt plantation.

LITERATURE REVIEW

Importance of eucalypts

The genus *Eucalyptus,* commonly called “eucalypts” or “gum trees”, belongs to the plant family Myrtaceae and is almost entirely native to Australia with only two species not found there: *E. urophylla* in Timor and some adjacent islands of Indonesia and *E. deglupta* in Papua New Guinea, Irian Jaja and the Moluccas of Indonesia, and Mindanao in the southern Philippines. Among large genera of woody plants, the genus *Eucalyptus* is confined to a single compact region of the globe and essentially to one continent, ranging between latitudes 9°N for *E. deglupta* and 44°S for *E. obliqua* and other species (Eldridge *et al*., 1997).

Eucalypts are widely known throughout the world as a remarkably wide range of tree species in regard to adaptation to sites, types of management systems, and variety of uses, both in natural forests and in plantations. Besides the homeland of Australia and its northern neighbors, eucalypts can be grown in most of the tropical and temperate climatic regions of the world between latitudes 40°N and 45°S (Eldridge *et al*., 1997). In Australia, eucalypts in natural forests produce a greater variety of wood products, e.g. high-quality sawn timber for furniture and joinery, construction timber for frames of houses, railway sleepers, pulpwood, compared to the fast growing plantations in other countries, while the extraction of the oils contained in the foliage is another important feature. But, throughout the world, eucalypts are cultivated to meet a wide range of needs, including pulpwood, charcoal and fuel wood, poles, mining timbers, fireboard, and amenity planting, as well as volatile oils for pharmaceutical and industrial uses (Boland *et al.*, 1984; Eldridge *et al*., 1997). In Thailand, eucalypt wood has been supplied largely for pulp, woodchip, and MDF industries, respectively (Luangviriyasaeng, 2003).

The world’s total area of eucalypt plantations have increased from 6 million ha in 1985 (Eldridge *et al*., 1997) to more than 17 million ha in 2000, accounting for almost 10% of the world’s total area of plantations. Currently, India, Brazil and China

are major countries occupying the largest plantation area of eucalypts in the world, while a number of countries have eucalypt plantation estimated to be more than 0.5 million ha each, including Australia, South Africa, Portugal, Vietnam and Thailand (FAO, 2001a). Probably, more than 60 other countries grow eucalypts in small-scale plantations, woodlots, windbreaks, and ornamental plantings.

Eucalypts in plantations

Performance of a eucalypt species on a particular site is generally the result of the interaction between the genetic and environments including climatic, edaphic, and other physical and biological factors. A mean annual increment (MAI) of 10-15 m^3 ha^{-1} yr^{-1} of stem wood is commonly obtained from the already large areas of eucalypt plantations in temperate and tropical regions (Eldridge *et al*., 1997) but variations in plantation yields can be observed, ranging from 15–26 m^3 ha^{-1} yr^{-1} (Brown, 2000) to 46 m^3 ha^{-1} yr^{-1} in Brazil (Seling *et al*., 2001) or 60 m^3 ha^{-1} yr^{-1} in China (Bai *et al*., 2003). In addition, small sample plots of eucalypts aged 6-8 years in Africa, Brazil, and Papua New Guinea have grown quickly at the rate of 70-90 m^3 ha^{-1} yr^{-1} of stem wood (Eldridge *et al*., 1997). General speaking, faster growth rates of eucalypts in plantations can be obtainable following careful site preparation, intensive silvicultural practices, selection of the best species and provenances, and genetic improvement.

The obvious success of many eucalypt plantations in fast producing large amounts of useful wood has led to some subsequent planting based more on enthusiasm than wisdom. Eldridge *et al*. (1997) emphasized that eucalypts should only be planted on a large scale in sites that are suitable for eucalypts, and only after appropriate land use planning. In some cases, new plantations of eucalypts may be unsuitable leading to low survival and poor growth because they are: (1) composed of species or provenances poorly adapted to the site; (2) poor genotypes of a species and provenances that would normally be expected to be successful on the site; (3) the wrong species for the end use desired; or (4) socially unacceptable in particular locality for one or more reasons. However, these constraints can be minimized or

avoided by undertaking: (1) site assessment and classification followed by better matching of species to site; (2) installation of well-designed species and provenance trials; (3) better consideration of wood properties and end uses; and (4) consultation with local people and end users on the kind of plantation or tree planting scheme desired and products needed.

Some important eucalypts

Eucalyptus camaldulensis

E. camaldulensis, river red gum, is one of a few eucalypts commonly known in Thailand during the last two decades as a commercial species with an outstanding role in economic and social points of view. It is a fast growing, medium-sized to tall tree to 30 m high. Of all eucalypts, *E. camaldulensis* has the widest distribution in Australia, ranging from latitude of 12°48´S on the Mary River in the northern Territory to 38°15´S in southwestern Victoria (CPBR, 2005). In the hot, dry inland, it is confined on watercourses where the trees rely on ground water stored from infrequent flooding. It can also found on a variety of soil types (Eldridge *et al*., 1997).

Due to its natural adaptation to both temperate and tropical climates, *E. camaldulensis* is the most widely planted tree species in arid and semi-arid regions around the world, primarily in timber plantations (CPBR, 2005). It adapts to a wide range of soil conditions, from very poor to periodically flooded, but changes in soil type within short distances may result in extreme changes in growth (Nieto and Rodriguez, 2005). In Thailand, this species can be planted on a wide range of site conditions where the annual precipitation is between 400–2,500 mm, and it can also endure droughts up to 2-8 months long (Viriyabuncha *et al.*, 1996). According to FAO (2001b), *E. camaldulensis* plantation yields in the drier tropics are often about 5-10 $m^3\ ha^{-1}\ yr^{-1}$ on 10-20 year rotations, whereas in moister regions, volumes up to 30 $m^3\ ha^{-1}\ yr^{-1}$ can be achieved. In younger ages, its MAI at 4.5 years varied between 12.5 and 17.6 $m^3\ ha^{-1}\ yr^{-1}$.

In its natural distributions, *E. camaldulensis* wood is used mainly for heavy construction, railway sleepers, flooring, framing, fencing, plywood and veneer manufacture, firewood and charcoal, while the extraction of the oils contained in the foliage can be produced commercially (Boland *et al.*, 1984). In Thailand, *E. camaldulensis* wood is supplied largely for pulp, woodchip, and MDF industries, respectively (Luangviriyasaeng, 2003).

Eucalyptus globulus

E. globulus, commonly called “southern blue gum” or “Tasmanian blue gum”, is an evergreen tree native to Australia. The natural distribution is between 38°26´S and 43°30´S, including Tasmania and southern Victoria of Australia.The species typically grows from 30 to 55 m tall. The tallest currently known specimen in Tasmania is about 90 m tall.

E. globulus is the most common plantation hardwood in Australia. It comprises 65% of all plantation hardwood in Australia with approximately 450,000 ha planted (Parsons *et al.*, 2006). It was the first of many euclaypts to become widely known outside Australia for its timber, and sometimes for extraction of eucalypt oil from its leaves. The plantations of *E. globulus* are commonly in areas of mild climate free of severe frosts and without severe droughts. The wood is used largely for pulpwood because of its bark, acceptable in most pulping processes, thereby adding greatly to the yield. The species is also a major source of fuel wood in many countries of the world primarily because of its ability to coppice after harvesting (Anonymous, 2007). MAI of 30 to 35 m^3 ha^{-1} yr^{-1} can be obtained on the most favorable sites, e.g. Argentina, Australia, Ethiopia (FAO, 2001b), but generally 10 to 15 m^3 ha^{-1} yr^{-1} is regarded as an achievable yield for *E. globulus* over large areas (Eldridge *et al.*, 1997).

Eucalyptus deglupta

E. deglupta, commonly known as “rainbow gum”, is the only eucalypt found naturally in northern hemisphere and, with *E. urophylla*, one of only two eucalypt species not occurring in Australia. The tree gets its common name from the striking stripes of color on its trunks and limbs. Patches of outer bark are shed annually at different times, showing the bright-green inner bark. This then darkens and matures to give blue, purple, orange and then maroon tones (Garner, 2006). It usually is a large tree 35-60 m high, but occasionally up to 75 m, with diameters of 0.5-2 m or greater (Eldridge *et al*., 1997).

E. deglupta is a tree species that has great potential for planting in wet tropical lowlands. The excellent growth rates of 25-40 m^3 ha^{-1} yr^{-1} over 15 years are common in several countries (Eldridge *et al*., 1997). Some major industrial projects have been focused on the tropics based, at least in part, on reforestation using this species in fast-growing plantations, for short rotations of 10-12 years or less. Currently, the tree is cultivated widely around the world, mainly for pulpwood used in making paper, particularly the pulpwood plantations in the Philippines (National Resources Institute, 2007). Despite the spectecular growth rate and suitability for pulping, the initial enthusiasm for planting in many countries has been tempered somewhat by experience in plantations where the species was not well enough matched to site. It is extremely site-sensitive, very susceptible to fire, low coppicing ability, and susceptible to several pests and diseases. However, provenance variation in these characteristics has been observed to match provenances/clones to site, thereby leading to rather successful tree improvement (Eldridge *et al*., 1997).

Eucalyptus urophylla

E. urophylla is one of the two eucalypts, which do not occur in Australia: the other is *E. deglupta* as mentioned earlier. It is a forest tree usually reaching 25-45 m in height and up to 1 m diameter, with a straight bole for half to two-thirds of the tree height. The natural range is commonly found in Timor and some adjacent islands of

Indonesia, which locates within the wet/dry tropics climatic region with a dry season varying from about 2 to 8 months and annual rainfall of 600-2,500 mm. It generally occurs over an altitudinal range from about 70 m to about 1,100 m with the exception of a few locations in Timor, above 1,000 m and up to 2,960 m (Eldridge *et al*., 1997).

E. urophylla is one of the best low-latitude eucalypts for planting in tropical areas. In recent years, it has increased greatly in popularity for plantations in humid and sub-humid tropical climates with several months of drought, for example in parts of Indonesia, Brazil, and southern China. Some measurements confirmed that, over a rotation of about 8 years on a suitable, well-prepared site, an MAI of 30 m^3 ha^{-1} yr^{-1} is obtainable following provenance screening. This growth rate was exceeded by selected hybrids of this species with *E. alba*, *E. grandis*, or *E. tereticornis*, followed by mass propagation by cuttings (Eldridge *et al*., 1997). The genetic gain in volume production of *E. urophylla* in China was increased up to 26% through genetic thinning to eliminate poor families and retain superior families in seed orchards (Xu *et al*., 2003). While, for the advanced clonal seed orchard established with superior trees selected, the estimated gain could be up to 31% compared to imported commercial seed stand (Huang *et al*., 2003). In contrast to its good growth in the wet/dry tropics, poor performance of *E. urophylla* in humid tropical lowlands in Madang, Papua New Guinea, on areas harvested for wood chips, was also observed (Eldridge *et al*., 1997). In consistence with *E. deglupta*, matching provenances/clones to site must be taken into consideration prior to the plantation establishment.

Eucalypt plantations in Thailand

Introduction of eucalypts to Thailand

Australian tree species, particularly eucalypts, have been extensively planted outside their natural distributions. Various species of eucalypts have been actively planted over 60 countries in every part of the world with the total area of more than 17 Million ha, 46% of which have been in Asia. In Thailand, *E. globulus* was first introduced from Australia as ornamental trees in 1911 but eucalypt planting

experiment was taken place later in 1950 in Chiang Mai with 5 species, i.e. *E. alba, E. citriodora, E. grandis, E. paniculata* and *E. saligna* (Pothisaro, 1985). In 1964, the Royal Forest Department (RFD) brought eucalypt seeds of 15 species, including *E. camaldulensis,* for planting experiments in 4 Forest Experimental Stations in the north (Chiang Mai), south (Surat Thani), west (Kanchaburi) and northeast (Sri Saket) under the Project on Survey of Pulp and Paper Raw Material. Remnants of these planting are still evident at these stations (Pousajja, 1993). After the Thai-Danish Pine and Fast-Growing Tree Improvement project was set up in 1973, new species/provenance trials of eucalypts were established. Subsequently, *ex-situ* gene conservation stands of selected species including *E. camaldulensis* were planted and these stands later became seed production sources for most of the early commercial and general plantings (Thaiutsa *et al*., 2004).

The results from species introduction trials have indicated suitable species for planting in Thailand under different ecological environment as suggested by Luangviriyasaeng (2003):

1. Species for dry lowlands (1,000-1,200 mm annual rainfall) including *E. brassianna, E. camaldulensis, E. citriodora,* and *E. tereticornis*;
2. Species for moist sites (1,500 mm annual rainfall) including *E. urophylla*; and
3. Species for high-altitude sites including *E. grandis*, and *E. saligna*.

The suitability of *E. camaldulensis* and *E. urophylla* for planting in many parts of Thailand was later confirmed by the trials supported by Australian Centre for International Agricultural Research (ACIAR) and CSIRO Forestry and Forest Products. The most adaptable and promising seed source of *E. camaldulensis* was Petford, Queensland as revealed by most experimental plantings (Luangviriyasaeng, 2003).

Commercial plantations

Commercial planting of eucalypts started in 1983 but the expansion of eucalypt plantation had been slowed down only 3 years afterwards due to a widespread of protest against eucalypt (Thaiutsa and Taweesuk, 1987). Consequently, the RFD in cooperation with the Agricultural Science Association of Thailand and the Soil Fertilizer Association of Thailand organized the seminar, which concluded that eucalypt had no threats to environments but the impact of large-scale monoculture of eucalypt needed continuous observations (Thaiutsa, 1987). Later on, the acute demand for wood because of a rapid expansion of wood-based industries has led to a rapid increase in eucalypt planting by farmers and private companies. The total area of eucalypt plantations in 1986 was 53,525 ha (Thaiutsa and Taweesuk, 1987) compared with the total area of 438,524 ha in 1997, distributed mainly in the northeast (47%) and east (29%) regions of the country (Sunthornhao, 1999). The total area of industrial eucalypt plantation in 2001 was 480,000 ha, with a total production capacity of solid wood of 19 million tons, and the current annual planting rate is 40,000 ha, mainly by private companies and a large number of small farmers, using a 4- or 5-year rotation (Luangviriyasaeng, 2003).

Most plantations were initially established with poor genetic quality seedlings produced by local nurseries leading to extremely variable growth and form. In recent years, high quality seedlings that can be produced by larger and better nurseries operated by large companies are largely required. According to Thaiutsa (2002), up to 80% of the current nursery stock is produced by stem cutting, while seedlings produced by tissue culture technique and from seeds account for only 12 and 8%, respectively.

Improvement of eucalypt clones or planting materials suitable for planting on particular site conditions may play a key factor for the success of eucalypt cultivation. Productivity of 5-year-old *E. camaldulensis* of the best clone planting was up to 28.9 t ha^{-1} yr^{-1} compared to only 14.5 and 12.0 t ha^{-1} yr^{-1} from the poorest clone and seedling plantings, respectively (Aramsri, 1999). High productivity can be, therefore,

expected if site selection, clone selection, and plantation management are based on appropriate silvicultural practices. Initially, the improvement programs for *E. camaldulensis* had emphasized only on rapid growth of straight and tall trees. Although clonal plantations have been impressive in growth and form, only small number of clones have been used for the operational planting by private companies leading to the outbreak of foliar pathogen (*Crytosporiopsis eucalypti*) in 1999 (Luangviriyasaeng, 2003). Subsequently, some major private companies have paid more attention to the improvement program and imported a large number of individual eucalypt families to establish breeding populations with a broad genetic base. Some improvement programs are recently focusing on breeding superior eucalypts that not only exhibit rapid growth, good form, and disease resistance, but also possess wood with superior pulp properties. While breeding programs of eucalypt hybrids are now in the way for selection of genotypes with disease resistance and wide adaptability (Luangviriyasaeng, 2003).

Site suitability and growth of eucalypts

Establishment of commercial plantations for high productivity depends primarily on planting materials, site conditions and environment, and plantation management. Among these factors, site conditions and environment, often called site quality, the assessed productive capacity of a particular site, has the greatest and often longest-lasting effect on differences in the productivity of various indigenous and plantation forests. The important components of site quality often include soil depth and drainage, soil physical and chemical composition (including soil reactions), amount and pattern of yearly soil moisture availability, frequency and nature of common and occasional winds, storms and fires, and the general climate of the area (FAO, 2002).

Soil suitability, specifically soil series, is also of great importance for planting eucalypts since soil series vary with environmental factors and affect growth and yield of eucalypts. Although eucalypt can grow well under different soil conditions ranging from humid to arid areas, low to high fertility, saline to acid soil (Homchan *et al*.,

1989), the great variations in growth and yield of the plantations established in different sites have been widely reported. An evaluation of the site quality for *E. camaldulensis* by a means of an edaphically index methodology indicated significant difference between the two planting sites in Argentina (Barido'n *et al*., 2001). The yield of 13-year-old eucalypt plantations in Thailand also varied greatly between planting sites, *i.e.* the yield of 148.1 t ha^{-1} from Khun Han (Sri Saket province) compared with 142.5, 61.9 and 60.0 t ha^{-1} of that from Somdet (Kalasin province), Dan Khun Thot (Nakhon Ratchasima province) and Mancha Kiri (Khon Kaen province), respectively (Wachrinrat, 1995). Furthermore, Insuan (2005) determined site potential for *E. camaldulensis* planting in the lower northeast part of Thailand and classified the site indexes into 5 classes based on soil series groups in the studied site. The finding suggested the significant relationship between the yield of eucalypt and some soil properties, *e.g.* clay particle, exchangeable potassium, available phosphorus, soil reaction.

Decision support system

Definition

The concept of decision support has evolved from two main areas of research, i.e. the theoretical studies of organizational decision making during the late 1950s and early 1960s, and the technical work on interactive computer systems in the 1960s, but the decision support development later became an area of research of its own in the middle of the 1970s (Marakas, 1999). Because there are many approaches to decision-making and because of the wide range of domains in which decisions are made, the DSS concept is very broad.

The term DSS has been used in many different ways and has been defined in various ways depending upon the author's point of view.

Little (1970) defined DSS by its process as a model-based set of procedures for processing data and judgments to assist a manager in his/her decision-making.

Gorry and Morton (1971) defined DSS by using type of problem and its system as an interactive computer-based system that helps decision makers utilize data and models to solve unstructured problems.

Marakas (1999) defined DSS as a system under the control of one or more decision makers that assists in the activity of decision-making by providing an organized set of tools intended to impart structure to portions of the decision-making situation.

For Turban and Aronson (2000), DSS is an interactive computer-based information system that helps decision makers to utilize data and models in order to solve unstructured management problems for improved decision-making. It basically utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights.

TechTarget (2004) developed the website containing technical knowledge about computer system and defined DSS as a computer program application that analyzes business data and presents it so that users can make business decisions more easily.

From those definitions, DSS can be concluded as an interactive computer-based system that helps decision makers solving unstructured problems by analyzing data and presenting them in the form of an easy-to-use interface.

Component

By its definition and concept, DSS can be divided into 4 components.

1. Data management system is the system used for data storage, retrieval, query, update and delete as well as report generator. It also prepares the data into the form that is ready to analyze in other processes.

2. Model management system is generally used to organize models derived from simulating the problem into mathematical equation(s) that can be analyzed by a computer system. In each step of problem solving, more than one of models may have to be involved.

3. Knowledge management system is developed, for some complicated problem solving cases, in order to support computer to perform its own capability. Such a technology as an Artificial Intelligent (AI) is a good example for this system.

4. Management system of user interface comprises computer hardware and software for communication between users and DSS. The user-friendly interactive concept of user interface designs is to make users understand the system step by step. The output of DSS can be in various forms such as text, graphic, chart or sound interactive.

Applications of decision support system in forestry

The DSS concept has been initially developed to solve unstructured problems in business but its applications have been widely used in other areas including forest ecology management.

Li *et al*. (2000) has developed a landscape model called LEEMATH to evaluate effects of management impacts on timber and wildlife habitat. This system is a tool for evaluating alternative management strategies from both economic perspective for timber management and ecological perspectives for wildlife habitat.

Spruce Budworm Decision Support System (SBW DSS), developed by the Canadian Forest Service from 1992 to 1996, is one of DSS applications on forest pest management. SBW DSS presents alternative management actions and facilitates incorporation of effects of insect damage into forest management planning. It permits evaluation of costs, benefits, and consequences of management, optimizes pesticide

use, and improves visualization of consequences of pest outbreaks and management strategies on forest performance indicators. (MacLean *et al*., 2000)

Jaber *et al*. (2001) used ground sensors, remote sensing, GIS, radio-communication, telecommunication, modeling, spatial analysis and AI model to develop the prototype of intelligence software for forest fire prevention and fighting.

Ecological management seems to be a very good example of applying the concept of DSS. Northeast Decision Model (NED) has been evolved into a decision support tool for managing both public and private forested land throughout the eastern United States. NED was designed to help managers providing ecological management planning to meet wildlife, ecology, water, and landscape objectives as well as timber production (Nute *et al*., 2002)

In silviculture, Exter (1998) studied the integrating GIS and multi-criteria analysis technique to combine species requirement and site attribute data for site and species. The system called Species Site Suitability (SPSISU) identified suitable areas for plantation establishment for each species, classified the areas according to a growth relationship, classed the suitability of the identified areas, and allocated one species over the other in areas where both were considered suitable. In addition, Vacik and Lexer (2001) developed DSS to select an appropriate silvicultural practice for forest plantation management by using water resources quality.

MATERIALS AND METHODS

Materials

1. Digital data of soil series from Land Development Department
2. Rainfall and temperature digital data from Thai Meteorological Department
3. Digital topographic map from Department of Water Resources
4. Administrative boundary from Department of Provincial Administration
5. Secondary growth data collection from privately-owned plantation
6. GPS Receiver
7. Microcomputer with software package
   - 7.1 ArcGIS
   - 7.2 MySQL
   - 7.3 UMN MapServer
   - 7.4 Statistical analysis software

Methods

Study site

The present study focused solely on eucalypt plantations in Chachoengsao province, well known as an industrial complex for major wood industries particularly woodchip and pulp industries. Specifically, privately-owned plantations available in the province were selected to obtain growth data in each soil series. The detailed information of the study site is described below.

Chachoengsao is a province in the eastern part of Thailand and also has a short coast to the Gulf of Thailand as depicted in Figure 1. The province is about 82 km east of Bangkok, occupying 5,351 km^2. It is administratively divided into 11 districts, i.e. Mueang Chachoengsao, Bang Khla, Bang Nam Priao, Bang Pakong, Ban Pho, Phanom Sarakham, Ratchasan, Sanam Chai Khet, Plaeng Yao, Tha Takiap and Khlong Khuean.

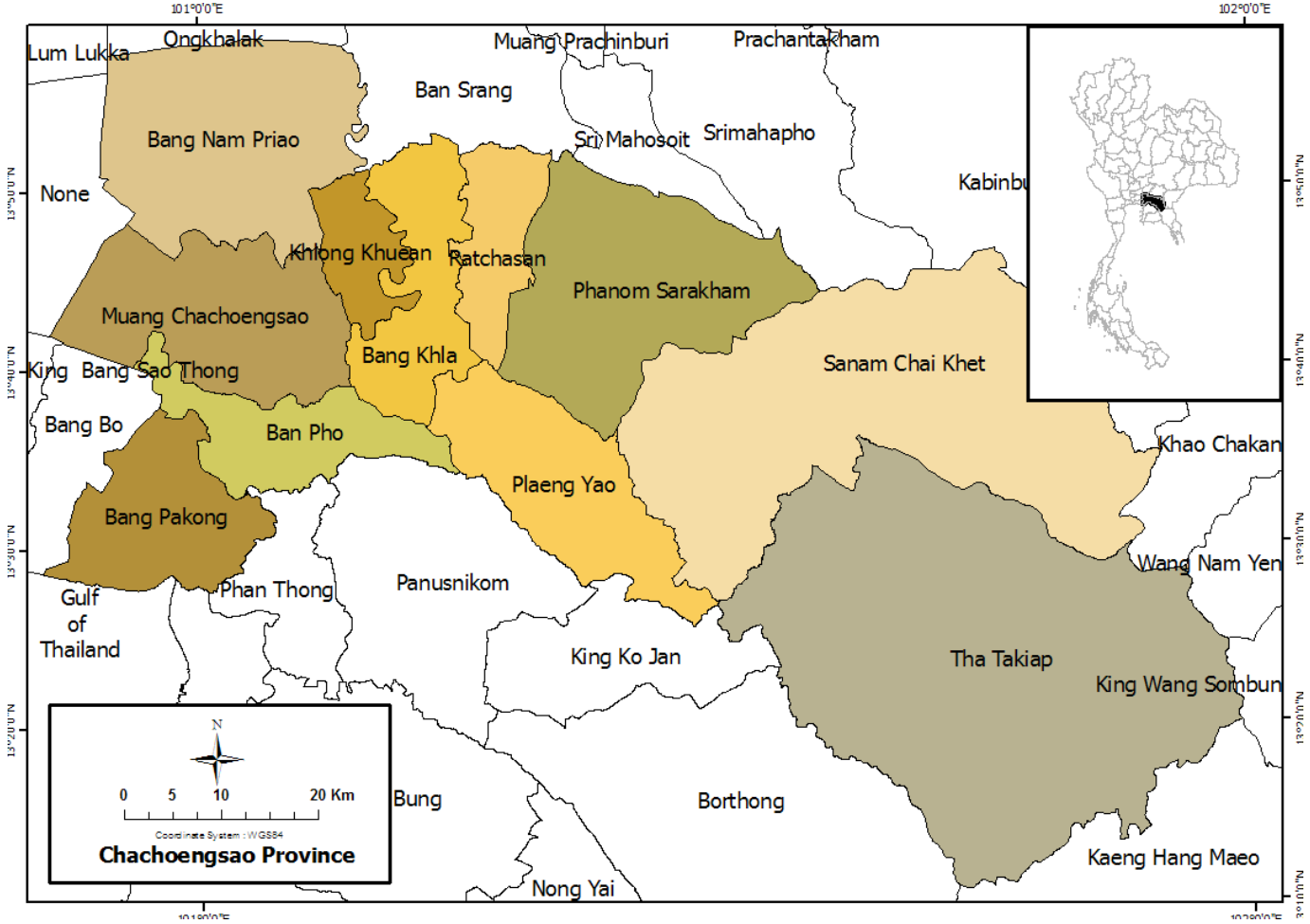


Figure 1 Administrative boundary of Chachoengsao province.

General area of Chachoengsao is low flat and basin, and the area adjacent to the sea is mangrove forest. Its low basin area is generally suitable for lowland cultivation especially rice, which is an economic crop providing the principal income to the province. By contrast, the eastern area, e.g. Sanam Chai Khet, Tha Takiap, is high and steep mountains, up to 300 m from the mean sea level. The majority of the population is farmers and the cultivated cash crops are corn, sugar cane, tapioca, cotton, rice, depending on their location and seasons. The provincial government has successfully promoted growing of fruits and Para rubber. The region is in the way to develop a large-scale business or industry.

The province has tropical monsoon with the mean annual rainfall of 1,297.62 mm, based on 32-year statistics (during 1975-2007) derived from the Thai Meteorological Department in 2008. The mean annual values of average, minimum, and maximum temperature were 27.69, 19.08, and 32.80°C, respectively. The average annual meteorological data during 1995-2007 is shown in Table 1.

Table 1 Mean annual rainfall and mean, minimum, and maximum temperature in Chachoengsao Meteorological Station during 1975-2007

Month	Rainfall (mm)	Temperature (°C)		
		Average	Minimum	Maximum
January	5.01	26.07	19.83	32.05
February	22.22	27.18	21.03	33.74
March	107.57	28.78	23.41	35.32
April	141.18	29.36	24.43	35.56
May	175.06	28.83	24.83	33.73
June	116.17	28.63	24.88	33.54
July	145.68	28.44	16.32	32.60
August	158.96	28.08	16.10	32.12
September	237.57	27.86	15.92	31.82

Table 1 (Continued)

Month	Rainfall (mm)	Temperature (°C)		
		Average	Minimum	Maximum
October	160.18	27.37	15.39	31.52
November	21.95	26.38	14.01	31.20
December	6.07	25.28	12.75	30.41
Dry season	464.18	28.37	18.69	32.83
Wet season	833.44	27.20	19.61	32.76
Total	**1,297.62**	**27.69**	**19.08**	**32.80**

DSS development

The DSS development consists of four main sessions as summarized in the conceptual framework, i.e. data preparation, data collection, data analysis, and DSS design (Figure 2).

1. Data preparation

The spatial data set comprising administrative boundary derived from the Department of Provincial Administration in 2004, land-use classification from the National Parks, Wildlife, and Plant Conservation Department in 2000, rainfall and temperature distribution from the Thai Meteorological Department in 2008, and topographic map from the Department of Water Resources was prepared for system database. The digital map cooperated with soil series in Chachoengsao province derived from Land Development Department (LDD) was used. Brief description of each soil series was given to compare soil properties (Appendix). The classification of soil series group for soil suitability for eucalypts was defined by the LDD (Soil Survey and Classification Division, 2000) as follows:

Soil suitability class I: suitable soil for eucalypt planting;
Soil suitability class II: fairly unsuitable soil for eucalypt planting; and
Soil suitability class III: unsuitable soil for eucalypt planting.

Furthermore, soil properties (soil depth 0-50 cm) of each soil series were gathered for the analysis of soil properties and eucalypt growth.

2. Data collection

2.1 Growth and yield of eucalypts

The soil suitability map for eucalypt planting defined by the LDD (Soil Survey and Classification Division, 2000) was used to locate sampling plots in privately-owned plantations of all soil series, where eucalypt plantations were mainly established. Such soil series were classified mainly as suitable (14 soil series) and partly as fairly unsuitable (9 soil series). Number of sampling plots for each soil series depended on land area, variation in soil properties, and existing plantation areas. The sampling plots of different ages, 2-5 years old, were scattered throughout each soil series. Practically, the sampling plots were undertaken on the plantations, which were established with different genetically-improved clones well adapted to the site and with intensive management. However, samples were not taken from fairly unsuitable or unsuitable soils where eucalypt plantations did not exist. For each sampling plot, the location was undertaken using GPS and mean diameters at breast height (DBH) and heights of eucalypts were obtained. Table 2 presents detailed information of all sampling plots used for growth and yield analysis.

2.2 Management and financial practices

Details and costs of plantation establishment and management, including land rent, site preparation, seedlings, planting, silvicultural practices, timber harvesting and transportation was obtained by interviews with plantation entrepreneurs and farmers in the study area.

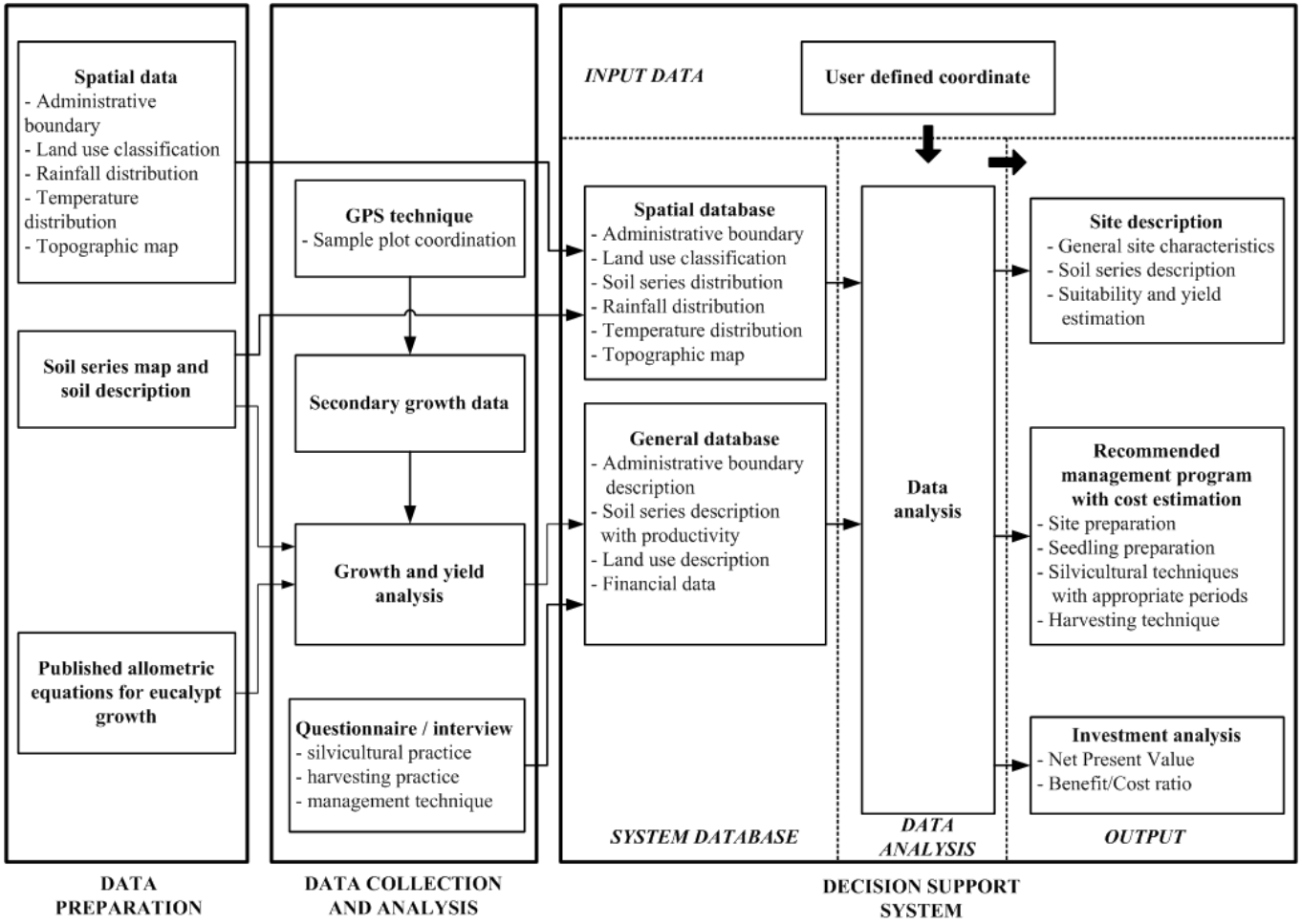


Figure 2 A conceptual framework of the DSS for eucalypt plantation investment in Chachoengsao province.

Table 2 Sampling plots used for growth and yield analysis in the DSS for eucalypt plantation investment in Chachoengsao province

Soil series	Age (years)	Number of plots	Location
Soil suitability class I: suitable			
Alluvial terrace and fan complex			
Bang Khla series (Bka)	2	1	Lad Krating sub-district, Sanam Chai Khet district
		1	Nong Mai Kaen sub-district, Plaeng Yao district
		1	Plaeng Yao sub-district, Plaeng Yao district
		4	Tha Kadan sub-district, Sanam Chai Khet district
	3	2	Nong Mai Kaen sub-district, Plaeng Yao district
		4	Tha Kadan sub-district, Sanam Chai Khet district
		3	Thung Pra Ya sub-district, Sanam Chai Khet district
	4	2	Lad Krating sub-district, Sanam Chai Khet district
		3	Tha Kadan sub-district, Sanam Chai Khet district
		2	Thung Pra Ya sub-district, Sanam Chai Khet district
	5	3	Tha Kadan sub-district, Sanam Chai Khet district
		1	Tha Takiap sub-district, Tha Takiap district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
Bang Khla and Bang Khla, brown soils (Bka&Bka-br)	2	9	Tha Kadan sub-district, Sanam Chai Khet district
		1	Tha Takiap sub-district, Tha Takiap district
	3	9	Tha Kadan sub-district, Sanam Chai Khet district
		1	Tha Takiap sub-district, Tha Takiap district
	4	5	Tha Kadan sub-district, Sanam Chai Khet district
	5	3	Tha Kadan sub-district, Sanam Chai Khet district
Bang Khla, brown variant (Bka-br)	2	1	Ko Khanun sub-district, Phanom Sarakham district
		5	Lad Krating sub-district, Sanam Chai Khet district
	3	6	Lad Krating sub-district, Sanam Chai Khet district
	4	1	Lad Krating sub-district, Sanam Chai Khet district
Don Rai series (Dr)	2	2	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Ko Khanun sub-district, Phanom Sarakham district
	3	6	Ko Khanun sub-district, Phanom Sarakham district
	4	3	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Ko Khanun sub-district, Phanom Sarakham district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
Pang Rai series (Pg)	2	6	Khao Hin Sorn sub-district, Phanom Sarakham district
	3	5	Khao Hin Sorn sub-district, Phanom Sarakham district
	4	5	Khao Hin Sorn sub-district, Phanom Sarakham district
	5	6	Khao Hin Sorn sub-district, Phanom Sarakham district
Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)	2	5	Thung Pra Ya sub-district, Sanam Chai Khet district
	3	5	Thung Pra Ya sub-district, Sanam Chai Khet district
	4	5	Thung Pra Ya sub-district, Sanam Chai Khet district
	5	1	Thung Pra Ya sub-district, Sanam Chai Khet district
Satuk series (Suk)	2	1	Ko Khanun sub-district, Phanom Sarakham district
		4	Nong Han sub-district, Phanom Sarakham district
	3	2	Khao Hin Sorn sub-district, Phanom Sarakham district
		2	Nong Han sub-district, Phanom Sarakham district
		1	Nong Mai Kaen sub-district, Plaeng Yao district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
	4	2	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Nong Mai Kaen sub-district, Plaeng Yao district
	5	1	Khao Hin Sorn sub-district, Phanom Sarakham district
Satuk, moderately deep variant (Suk-md)	2	2	Lad Krating sub-district, Sanam Chai Khet district
		1	Nong Mai Kaen sub-district, Plaeng Yao district
	3	2	Lad Krating sub-district, Sanam Chai Khet district
		1	Khlong Ta Krao sub-distrcit, Tha Takiap district
	4	4	Khlong Ta Krao sub-distrcit, Tha Takiap district
	5	6	Khlong Ta Krao sub-distrcit, Tha Takiap district
Warin series (Wn)	2	4	Ko Khanun sub-district, Phanom Sarakham district
		1	Nong Han sub-district, Phanom Sarakham district
	3	1	Khao Hin Sorn sub-district, Phanom Sarakham district
		3	Ko Khanun sub-district, Phanom Sarakham district
		1	Nong Han sub-district, Phanom Sarakham district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
	4	3	Khao Hin Sorn sub-district, Phanom Sarakham district
	5	3	Khao Hin Sorn sub-district, Phanom Sarakham district
Erosion surface and local wash			
Kabin Buri series (Kb)	2	2	Lad Krating sub-district, Sanam Chai Khet district
		3	Thung Pra Ya sub-district, Sanam Chai Khet district
	3	5	Thung Pra Ya sub-district, Sanam Chai Khet district
	4	1	Lad Krating sub-district, Sanam Chai Khet district
		7	Thung Pra Ya sub-district, Sanam Chai Khet district
Lat Ya/Tha Yang association (Ly/Ty)	2	3	Khlong Ta Krao Subdistrcit, Tha Takiap district
		2	Thung Pra Ya sub-district, Sanam Chai Khet district
	3	2	Khlong Ta Krao sub-distrcit, Tha Takiap district
		3	Thung Pra Ya subdistrict, Sanam Chai Khet district
	4	3	Thung Pra Ya subdistrict, Sanam Chai Khet district
Sattahip series (Sh)	2	3	Khao Hin Sorn subdistrict, Phanom Sarakham district
	3	3	Khao Hin Sorn subdistrict, Phanom Sarakham district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
	4	3	Khao Hin Sorn sub-district, Phanom Sarakham district
	5	4	Khao Hin Sorn sub-district, Phanom Sarakham district
Sattahip, gravelly variant (Sh-gr)	2	4	Hua Sam Rong sub-district, Plaeng Yao district
Satuk, granite derived variant (Suk-gra)	2	4	Khao Hin Sorn sub-district, Phanom Sarakham district
		4	Tha Kadan sub-district, Sanam Chai Khet district
	3	4	Khao Hin Sorn sub-district, Phanom Sarakham district
	4	5	Khao Hin Sorn sub-district, Phanom Sarakham district
Tha Yang series (Ty)	2	3	Nong Mai Kaen sub-district, Plaeng Yao district
	3	3	Hua Sam Rong sub-district, Plaeng Yao district
Soil suitability class II: fairly unsuitable			
Alluvial terrace and fan complex			
Alluvial soils, poorly drained complex (AC-pd)	2	3	Khao Hin Sorn sub-district, Phanom Sarakham district
	3	1	Khao Hin Sorn sub-district, Phanom Sarakham district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
Alluvial soils well drained complex (AC-wd)	2	3	Tha Kadan sub-district, Sanam Chai Khet district
	3	3	Tha Kadan sub-district, Sanam Chai Khet district
Chon Buri series (Cb)	2	1	Khao Hin Sorn sub-district, Phanom Sarakham district
	3	3	Hua Sam Rong sub-district, Plaeng Yao district
Hin Kong series (Hk)	2	5	Nong Mai Kaen sub-district, Plaeng Yao district
	3	1	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Nong Mai Kaen sub-district, Plaeng Yao district
		3	Thung Pra Ya sub-district, Sanam Chai Khet district
	4	3	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Thung Pra Ya sub-district, Sanam Chai Khet district
	5	4	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Nong Mai Kaen sub-district, Plaeng Yao district
Hin Kong / Ko Khanun association (Hk/Kkn)	2	5	Tha Kadan sub-district, Sanam Chai Khet district
		1	Tha Takiap sub-district, Tha Takiap district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
	3	2	Tha Kadan sub-district, Sanam Chai Khet district
		1	Tha Takiap sub-district, Tha Takiap district
	4	5	Tha Kadan sub-district, Sanam Chai Khet district
	5	3	Tha Kadan sub-district, Sanam Chai Khet district
Ko Khanun series (Kkn)	2	3	Khao Hin Sorn sub-district, Phanom Sarakham district
	3	3	Khao Hin Sorn sub-district, Phanom Sarakham district
	4	1	Khao Hin Sorn sub-district, Phanom Sarakham district
		2	Tha Takiap sub-district, Tha Takiap district
Phen series (Pn)	2	3	Thung Pra Ya sub-district, Sanam Chai Khet district
	3	3	Thung Pra Ya sub-district, Sanam Chai Khet district
	4	3	Thung Pra Ya sub-district, Sanam Chai Khet district
Sakon series (Sk)	2	3	Tha Kadan sub-district, Sanam Chai Khet district
	3	2	Tha Kadan sub-district, Sanam Chai Khet district

Table 2 (Continued)

Soil series	Age (years)	Number of plots	Location
Erosion surface and local wash			
Ban Bueng series (Bbg)	2	1	Khao Hin Sorn sub-district, Phanom Sarakham district
		4	Tha Kadan sub-district, Sanam Chai Khet district
	3	5	Tha Kadan sub-district, Sanam Chai Khet district
	4	2	Khao Hin Sorn sub-district, Phanom Sarakham district
		1	Lad Krating sub-district, Sanam Chai Khet district
		1	Tha Kadan sub-district, Sanam Chai Khet district
	5	4	Khao Hin Sorn sub-district, Phanom Sarakham district

3. Data analysis

3.1 Growth and yield data analysis

Growth data, derived from sampling plots as mentioned earlier in section 2.1, was used to calculate aboveground biomass (stem, branch and leaf dry weight) and economic production (stem fresh weight) by using allometric equations following to Wachrinrat (2003) as presented in Table 3.

Table 3 Allometric equations for estimation of eucalypt production in the first rotation (seedling stand)

Age (years)	Production	Equations	R^2
1	Stem biomass	$W_s = 0.0338 (DBH^2H)^{0.8406}$	0.9942
	Branch biomass	$W_b = 0.0163 (DBH^2H)^{0.7446}$	0.9744
	Leaf biomass	$W_l = 0.0278 (DBH^2H)^{0.7096}$	0.9284
2	Stem biomass	$W_s = 0.0248 (DBH^2H)^{0.9205}$	0.9919
	Branch biomass	$W_b = 0.0008 (DBH^2H)^{1.1449}$	0.9914
	Leaf biomass	$W_l = 0.0141 (DBH^2H)^{0.7459}$	0.9870
3	Stem biomass	$W_s = 0.0318 (DBH^2H)^{0.8973}$	1.0000
	Branch biomass	$W_b = 0.0057 (DBH^2H)^{0.8631}$	0.9498
	Leaf biomass	$W_l = 0.0203 (DBH^2H)^{0.6257}$	0.8791
	Economic production	$W_{fs} = 0.08820 (DBH^2H)^{0.8896}$	1.0000
4	Stem biomass	$W_s = 0.0174 (DBH^2H)^{1.0118}$	0.9992
	Branch biomass	$W_b = 0.041 (DBH^2H)^{0.5310}$	0.9321
	Leaf biomass	$W_l = 0.0094 (DBH^2H)^{0.5843}$	0.8750
	Economic production	$W_{fs} = 0.04380 (DBH^2H)^{0.9968}$	0.9991

Table 3 (Continued)

Age (years)	Production	Equations	R^2
5	Stem biomass	$W_s = 0.0343 (DBH^2H)^{0.9251}$	0.9994
	Branch biomass	$W_b = 0.0108 (DBH^2H)^{0.7732}$	0.9584
	Leaf biomass	$W_l = 0.0022 (DBH^2H)^{0.8384}$	0.9461
	Economic production	$W_{fs} = 0.05810 (DBH^2H)^{0.9595}$	0.9996

where:

W_s = stem biomass (kg)

W_b = branch biomass (kg)

W_l = leaf biomass (kg)

W_{fs} = economic production or stem fresh weight (kg)

H = total height (m)

DBH = diameter at breast height, 1.30 m (cm)

Source: Wachrinrat (2003)

Differences in aboveground biomass and economic production between soil series were also compared. Relationship between aboveground biomass and stand age of each soil series was analyzed using statistical software. Site quality index of eucalypts planted on the soil series, where plantation growth was taken, were established using the relationship between stem biomass and ages according to an anamorphosis method (Prasomsin, 1991) on the basis of 3-year rotation and 3 classes, i.e. very good, good, and moderate site qualities. Presumably, the soil series classified in these site quality classes were suitable for eucalypt planting. Subsequently, the defined site quality for each soil series was prepared to produce site suitability map for the DSS database.

3.2 Relationship between soil properties and eucalypt growth

The relationship between soil properties and eucalypt growth was also studied. The multiple regressions between dependent variable of eucalypt production and the independent variables of 7 soil properties, i.e. sand, silt, clay, soil reactions, available phosphorus, total carbon, and base saturation was analyzed by the backward multiple regression analysis using the statistical software. All soil properties determined in the multiple regression analysis were generally recognized as important edaphic factors affecting tree growth and available in the present study.

4. DSS Design

DSS for eucalypt plantation investment in Chachoengsao province was developed in the web-based interactive system using PHP script. The UMN Internet MapServer was applied in the process of spatial data display and user defined location input, while the MySQL was used for database design. Due to user-friendly concept, the Thai system language was applied to simply communicate with Thai entrepreneurs and/or farmers. In addition, the proposed DSS was flexible to update system database for future uses and development and could be possibly applied for other planting areas. The DSS design can be separated into 4 main parts, namely system database development, database analysis system, user-interface management system, and system output as discussed below.

4.1 System database development

Secondary and field data collection was generated in the form of spatial and general data, described as system database in Figure 2. The system database was prepared for analysis with input data in other related processes. The spatial database, using GIS application, included administrative boundary, land use classification, soil series, rainfall, temperature, and topographic map, while the general database was description of administrative boundary, soil series and land use as well as financial database including costs of site management, silvicultural

practices, harvesting and transportation. Sets of commands were also generated for the system database manipulation, e.g. data updates, retrievals.

4.2 Data analysis system

Field data analysis was undertaken using the production models depending on site quality of each soil series. Sets of problem solving methods were also prepared for analysis of relevant input data.

Site potential was analyzed accordingly after coordinate of a location was input by a user. The input location of the defined area was then classified for site suitability based on site quality index analyzed in section 3.1.

Site suitability for eucalypt planting was generated and soil description and characteristics were provided as supporting information for plantation establishment and management. However, no further procedure was executed where the defined area belonged to the following categories: (1) outside the administrative boundary of Chachoengsao province; (2) water boundaries, e.g. river, canal, pond; and (3) protected areas, e.g. national parks, wildlife sanctuary, slope complex.

Yield estimation of the first rotation of seedling stand was analyzed using growth model according to the site quality of each soil series. The yield of eucalypt plantation was analyzed where the soil series was classified as suitable sites.

The relationship between growth and soil characteristics was analyzed to provide appropriate management practices of the defined area.

Appropriate silvicultural practices and management plan for each site condition was given including site preparation, weeding, fertilizer application, harvesting period. The information for each management process was provided for users.

Financial analysis was undertaken in each management process under different conditions depending on details informed by users. Net Present Value (NPV) was calculated to recommend users whether the investment of eucalypt plantation was economically worthwhile by the following equation:

$$NPV = \sum_{t=0}^{n} \left(\frac{CF_t}{(1+k)^t} \right) \quad (1)$$

where : n = total numbers of years (rotation)
CF = cash flows in year n
k = interest rate
t = years

The benefit-cost ratio (B/C ratio), ration of gross discounted benefits to gross discounted costs, was also calculated.

The appropriate harvesting period was recommended based upon yield estimation and financial analysis.

4.3 Management system of user interface

The management system of user interface was designed to communicate with users step by step. Location of the specified land was required by the DSS. Once the input data has been entered, the data analysis system was generated to provide recommendation of site suitability, yield estimation, appropriate management and silvicultural practices, and financial returns. The system was designed to help users finding their specified areas depending on their information. The map of Chachoengsao province was shown on the screen. Some commands such as ‘zoom’, ‘pan’ or ‘query input’ assisted users to find their specified locations, and users can subsequently input the locations directly on the computer screen. Alternatively, users can also input the geographic coordinate directly to the input data

box. Existing land use data was also required to provide information needed for appropriate plantation establishment and management.

4.4 System output

The system output was designed to provide information for investment of eucalypt plantation, e.g. site characteristics, site suitability, plantation yield, economical profits, and recommendation for plantation management. The details with text, table, or graphic formats were designed to display on screen and to print out as preferred.

DSS evaluation

To evaluate DSS that provides sufficient information for users, interviews with plantation entrepreneurs/farmers were periodically undertaken during the process of DSS development in order to include all essential data or information needed by users in the proposed design. Furthermore, growth data of other 34 sampling plots of 2- to 5-year old eucalypt plantations in 7 soil series, where growth data were not taken for the site quality analysis, were collected and the plantation yield was analyzed to compare with the yield obtained from the DSS in respective soil series.

RESULTS AND DISCUSSION

Database design

The system database as depicted in Figure 2 was designed and developed to meet all specific objectives of DSS for eucalypt investment in the present study. The system database consists of 11 entities, including 6 entities of spatial database and 5 entities of general database. The entity relation (ER) of the database design is shown in the ER diagram (Figure 3). Spatial database designed in the current study is composed of 6 entities, i.e. *SubDistrict*, *CCS_SoilSeries*, *LandUse*, *TopoMap*, *Rainfall*, and *Temperature*, as shown in the ER diagram (Figure 3).

The *SubDistrict* entity provides attributes related to administrative boundaries (sub-district) according to *SubDistrict* data dictionary as presented in Table 4.

The *CCS_SoilSeries* entity displays attributes of soil series classified for Chachoengsao province. Its data dictionary is also provided in Table 5.

The *LandUse* entity provides attributes related to land use classification for Chachoengsao province. Areas, not categorized within neither protected areas, nor water boundaries, are processed as possible areas for eucalypt planting. The land use classes are also given in the *LandUse* data dictionary (Table 6).

The *TopoMap* entity generally presents the topographic map used as a background map of Chachoengsao province.

The *Rainfall* entity provides attributes of rainfall distribution in Chachoengsao province as shown in the *Rainfall* data dictionary (Table 7).

The *Temperature* entity provides attributes of temperature distribution in Chachoengsao province as presented in the *Temperature* data dictionary in Table 8.

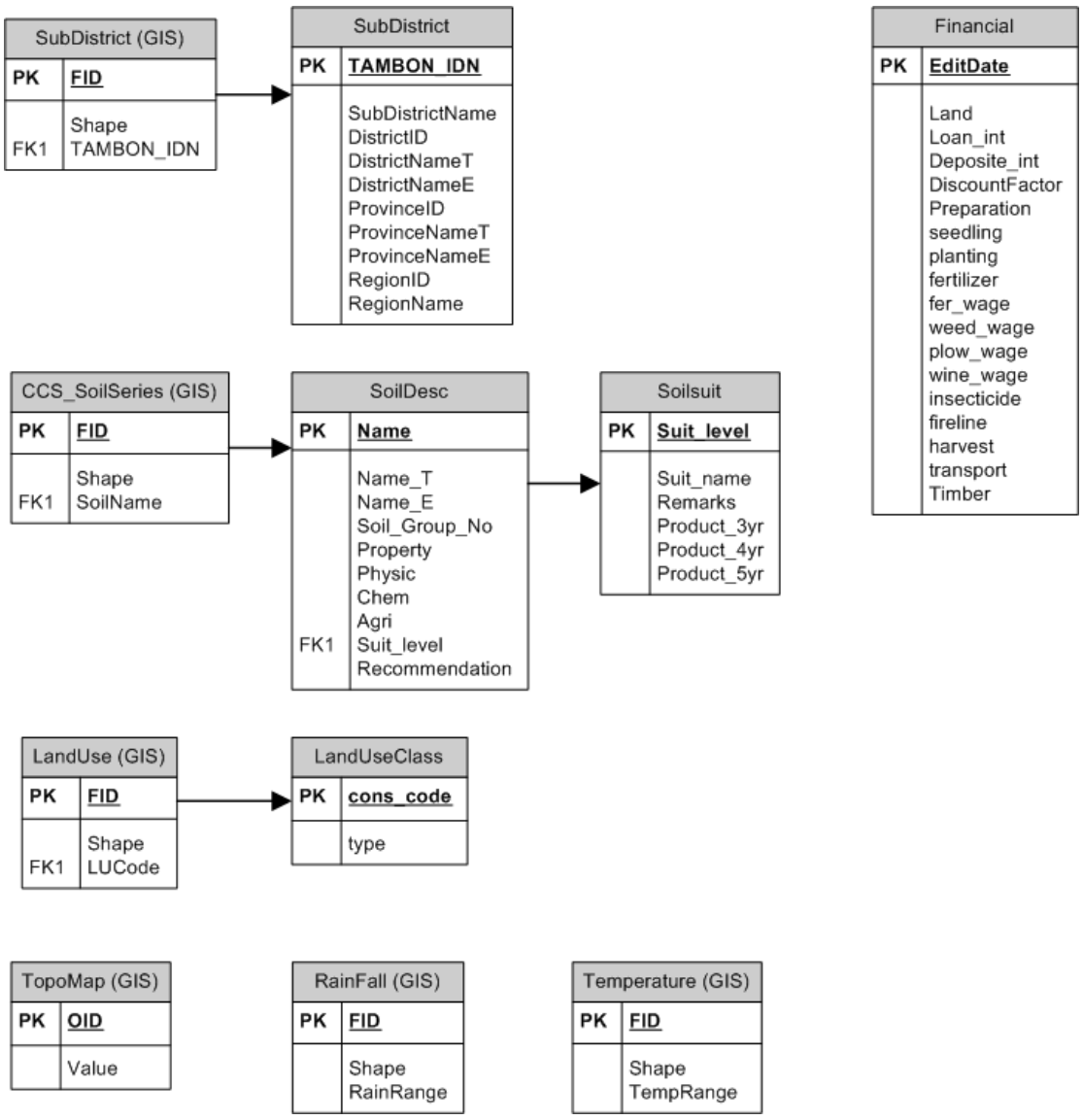


Figure 3 Entity relationship (ER) diagram of the DSS database design for eucalypt plantation investment in Chachoengsao province.

Table 4 Data dictionary of *SubDistrict* spatial data in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*SubDistrict*		
Description:	Store sub-district spatial data		
Column	Data type (Size)	Key	Description
FID	OID(4)	PK	Feature ID
Shape	Geometry(0)		Feature type
TAMBON_IDN	Text(6)	FK	Sub-district ID

Table 5 Data dictionary of *CCS_SoilSeries* spatial data in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*CCS_SoilSeries*		
Description:	Store soil series spatial data		
Column	Data type (Size)	Key	Description
FID	OID(4)	PK	Feature ID
Shape	Geometry(0)		Feature type
SoilName	String(40)	FK	Soil series ID

Table 6 Data dictionary of *LandUse* spatial data in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name: *LandUse*			
Description: Store land use classification spatial data			
Column	Data type (Size)	Key	Description
FID	OID(4)	PK	Feature ID
Shape	Geometry(0)		Feature type
LUCode	Number(11)	FK	Landuse classification code: 0=not within the following defined areas; 1=protected areas; and 2=water boundaries

Table 7 Data dictionary of *Rainfall* spatial data in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name: *Rainfall*			
Description: Store rainfall distribution spatial data			
Column	Data type (Size)	Key	Description
FID	OID(4)	PK	Feature ID
Shape	Geometry(0)		Feature type
RainRange	String(50)		Rainfall distribution

Table 8 Data dictionary of *Temperature* spatial data in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*Temperature*		
Description:	Store temperature distribution spatial data		
Column	Data type (Size)	Key	Description
FID	OID(4)	PK	Feature ID
Shape	Geometry(0)		Feature type
TempRange	String(50)		Temperature distribution

Of the 5 entities of general database, the 4 entities are integrated by the first 3 entities of spatial database, namely *SubDistrict*, *SoilDesc* and *LandUseClass* respectively as shown in Figure 3.

The *SubDistrict* entity consists of attributes containing general description of each sub-district in Chachoengsao province, i.e. sub-district name, district name, province name, region name.

The *SoilDesc* entity provides attributes related to general information on soil series, soil description, and soil suitability classification for eucalypt cultivation. Soil description, including general description, physical and chemical properties and recommendation for agricultural crop cultivation, is provided based upon the soil series group of the location. Recommendation for appropriate site preparation is also provided based on soil properties. All data of soil description are concluded accordingly in the *SoilDesc* data dictionary (Table 9).

Table 9 Data dictionary of *SoilDesc* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*SoilDesc*		
Description:	Store soil series description		
Column	Data type (Size)	Key	Description
Name	varchar(20)	PK	Soil series code
Name_t	varchar(255)		Soil series name in Thai
Name_e	varchar(255)		Soil series name in English
Soil_group_no	int(5)		Soil series group number
Property	Text		General soil property
Physic	Text		Physical soil property
Chem	Text		Chemical soil property
Agri	Text		Possibility for agricultural crops
Recommendation	Text		Recommendation for eucalypt plantation

Subsequently, classification of site suitability for eucalypt planting was developed based on site quality index of each soil series available and presented as the *SoilSuit* entity. Moreover, attributes of yield estimation on different periods of harvesting, 3-5 years, are given in this entity. Table 10 shows the *SoilSuit* data dictionary, which summarizes detail and productivity of each site quality classified for eucalypt planting.

Table 10 Data dictionary of *SoilSuit* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*SoilSuit*		
Description:	Store description of each site suitability class based on site quality index		
Column	Data type (Size)	Key	Description
Suit_level	Char(1)	PK	Site suitability class based on site quality index
Suit_name	varchar(255)		Site suitability class
Remarks	varchar(255)		Site suitability details
Product_3yr	int(5)		Productivity at 3- year rotation
Product_4yr	int(5)		Productivity at 4- year rotation
Product_5yr	int(5)		Productivity at 5- year rotation

The *LandUseClass* entity, an attribute containing description of land use classification, is given to provide possibility of areas where eucalypts could be cultivated. Protected areas and water boundaries cannot be used for eucalypt planting in any circumstances. The land use classification is given in the *LandUseClass* data dictionary (Table 11).

In addition to the 4 entities of general database mentioned earlier, the *Financial* entity is of great importance in providing financial data for investment analysis. It comprises of attributes containing costs per unit land area throughout the management program, e.g. land rent, site preparation, seedling preparation, tending, harvesting, and transportation, based upon the manual for eucalypt planting provided by the private eucalypt plantation owner in the study area. Timber price is also provided for estimation of financial returns. Moreover, loan and deposit interest rates and discount factor are given to analyze data in monetary terms. The financial dataset is listed in the *Financial* data dictionary as presented in Table 12.

Table 11 Data dictionary of *LandUseClass* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*LandUseClass*		
Description:	Store land use classification type with possibility for eucalypt planting		
Column	Data type (Size)	Key	Description
cons_code	char(1)	PK	Land use classification code
Type	Varchar(50)		Land use type

Table 12 Data dictionary of *Financial* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*Financial*		
Description:	Store predefined financial data for financial analysis		
Column	Data type (Size)	Key	Description
Land	Float		Price of land rent (baht/rai)
Loan_int	Float		Loan interest (%)
Deposit_int	Float		Fixed deposit interest (%)
Df	int(11)		Deflation rate (%)
Preparation	int(11)		Site preparation cost (baht/rai)
Seedling	int(11)		Seedling cost (baht/seedling)
Planting	int(11)		Planting cost (baht/rai)
Fertilize	int(11)		Fertilizer cost (baht/rai)
Fer_wage	int(11)		Fertilizer application cost (baht/rai)

Table 12 (Continued)

Table name:	*Financial*		
Description:	Store pre-defined financial data for financial analysis		
Column	Data type (Size)	Key	Description
Weed_wage	int(11)		Weeding cost (baht/rai)
Plow_wage	int(11)		Plowing cost (baht/rai)
Wine_wage	int(11)		Climbing weed cutting (baht/rai)
Insecticide	int(11)		Insecticide application cost (baht/rai)
Fireline	int(11)		Fire line construction cost (baht/rai)
Harvest	int(11)		Harvesting cost (baht/ton)
Transport	int(11)		Timber transportation cost (baht/ton)
Timber	int(11)		Timber price (baht/ton)
Editdate	Date	PK	Latest updated date

Furthermore, there are 2 tables of data dictionary, i.e. *SubDistrictBBox*, *DistrictBBox*, both of which are integrated to retrieve data and display results (Tables 13-14). The *UserTable* data dictionary is also provided to store user information for database management (Table 15).

Table 13 Data dictionary of *SubDistrictBBox* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*SubDistrictBBox*		
Description:	Store coordinates of sub-district boundary extent		
Column	Data type (Size)	Key	Description
Tambon_idn	char(6)	PK	Sub-district ID
Tam_code	char(2)		Sub-district Code
Tam_nam_t	varchar(100)		Sub-district name in Thai

Table 13 (Continued)

Table name:	*SubDistrictBBox*		
Description:	Store coordinates of sub-district boundary extent		
Column	Data type (Size)	Key	Description
Amphoe_idn	char(4)		District ID
Amphoe_code	char(2)		District Code
Xmin	int(11)		Minimum x coordinate for sub-district boundary
Ymin	int(11)		Minimum y coordinate for sub-district boundary
Xmax	int(11)		Maximum x coordinate for sub-district boundary
Ymax	int(11)		Maximum y coordinate for subdistrict boundary

Table 14 Data dictionary of *DistrictBBox* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*DistrictBBox*		
Description:	Store coordinates of district boundary extent		
Column	Data type (Size)	Key	Description
Amphoe_idn	char(4)	PK	District ID
Amphoe_code	char(2)		District code
Amphoe_t	varchar(100)		District name in Thai
Amphoe_e	varchar(100)		District name in English
Xmin	int(8)		Minimum x coordinate for district Boundary

Table 14 (Continued)

Table name:	*DistrictBBox*		
Description:	Store coordinates of district boundary extent		
Column	Data type (Size)	Key	Description
Ymin	int(8)		Minimum y coordinate for district Boundary
Xmax	int(8)		Maximum x coordinate for district Boundary
Ymax	int(8)		Maximum y coordinate for district Boundary

Table 15 Data dictionary of *UserTable* in the DSS database design for eucalypt plantation investment in Chachoengsao province

Table name:	*UserTable*		
Description:	Store system access user details		
Column	Data type (Size)	Key	Description
Userid	int(5)	PK	Auto_increment
Username	varchar(20)		User name
Password	varchar(20)		User password
Passwordmd5	varchar(32)		User password encryption code
Namethai	varchar(100)		Name in Thai
Nameenglish	varchar(100)		Name in English
Email	varchar(100)		e-mail address
Rightcode	char(3)		User right level code
Recentlogin	varchar(16)		Recent log in date/time

Table 15 (Continued)

Table name:	*UserTable*		
Description:	Store system access user details		
Column	Data type (Size)	Key	Description
Lastlogin	Varchar(16)		Last login date/time
Userstatus	char(1)		User status
Amountlogin	int(10)		Amount of login
Userpic	Varchar(30)		User picture

DSS is usually forced to address a number of critical requirements to accomplish all planning objectives. It evolves a somewhat simple and straightforward management approach based on a multiple-use concept to a complex multi-faceted process. Computer based modeling, particularly linear programming, has been applied to address the complex problems involved in the DSS for forest management. For instance, FORPLAN has been developed using linear and other programming techniques to determine economic and financial efficiency by optimizing land allocation and resource scheduling for USDA forest management (Kent *at. al*., 1991). Moreover, a spatial DSS has been developed to assist analysts and decision makers to link between spatial DSS and GIS for forest management planning (Church *et al*., 2000). In this study, simple growth model was applied to predict plantation yield according to site quality index integrated by related GIS database, e.g. topographic map, land use classification, soil series, climatic data. Site description and plantation yield as well as alternative management according to soil series and site qualities are given prior to decision making of eucalypt plantation investment.

Database analysis

Soil classification

Soil classification in Thailand, responsible by LDD, has been based on the USDA Soil Classification System, with an emphasis on soil morphology, physical and

chemical properties, and climatic conditions. Currently, there are more than 270 soil series in Thailand and they can be divided into 62 soil series groups. Based on the digital map in Chachoengsao province cooperated with soil series derived from LDD, the definition of soil mapping units used for soil description in Chachoengsao can be summarized into 6 categories according to LDD (1983) as shown in Figure 4 and Table 16.

(1) Soil series is a soil mapping unit with similar properties in soil taxonomy. A soil series name is generally derived from a town or landmark in or near the area where the soil series was first recognized, e.g. Bang Prakong series (Bpg), Bang Khla series (Bka), Kabin Buri series.

(2) Soil variant is a soil mapping unit with different soil taxonomy, that could be classified into another soil series, but occurring only in small patches, e.g. Bang Khla, brown variant (Bka-br).

(3) Soil association is a soil mapping unit composed of two or more soil series, developed on a similar parent material or on a combination of rocks, and occurring in the same geographical area. They could not be distinguished completely in either soil series, e.g. Lat Ya/Tha Yang association (Ly/Ty).

(4) Undifferentiated soil group is a soil mapping unit similar to soil association but not geographically related. It is not necessary to be categorized as a separate soil series, e.g. Don Rai and Korat soils (Dr&Kt), Satuk and Warin soils (Suk&Wn).

(5) Soil complex is a soil mapping unit consisting of two or more soil recognized classifications occurring together, and rather difficult to produce a soil map, e.g. Alluvial soils well drained complex (AC-wd).

(6) Soil phase is a subdivision of a soil series having features (for example, slope, surface texture, thickness and stoniness), but which do not vary sufficiently to differentiate it as a separate series, e.g. Klaeng, overwash phase (Kl-ow).

The result shows that there are 30 soil series and other 23 soil mapping units in Chachoensao province. However, soil series in this study refers to soil series and other 5 categories of soil mapping units. Brief description of each soil series is given to compare soil taxonomy, classification, and properties in the Appendix. According to LDD (1983), all soil series can be classified into 4 groups based on soil geology and parent materials, namely tidal flat, former tidal flat, alluvial terrace and fan complex, and erosion surface and local washes (Figure 5 and Table 16).

Firstly, soil series found on tidal flat, of which the parent material is non-acid marine and brackish water deposits, are generally clay and very poorly drained. Soil series in this group occupies only 0.93% of the total area, or 29,907.52 rai (Table 16). It occurs preferentially on flood plains along the Bang Pakong riversides (Figure 5). There are only Bang Pakong series (Bpg) and Tha-chin and Bang Pakong series (Tc&Bpg) found in this category.

Secondly, soil series occurring on former tidal flat, of which the parent material is acid marine and brackish water deposits, are mainly clay and poorly to very poorly drained. It covers 36.26% of the total land area or 1,162,124.22 rai (Table 16) and can be found largely on the western lowlands (Figure 5). The areas are mostly used for paddy field. This category comprises of 12 soil series, e.g. Bang Nam Priao series (Bp), Bangkok series (Bk), Ongkharak series (Ok), Rangsit series (Rs), Samut Prakan series (Sm).

Thirdly, soil series occur on the alluvial terrace and fan complex, of which the parent material is alluvium, local washes or transported materials. The soil texture varies greatly from sand to clay and the soil drainage ranges from poorly to well drained. This group occupies more than 38.61% of the total land area or 1,237,302.13 rai (Table 16). It occurs continuously from flood plain to low, middle, and high terrace on the eastern uplands (Figure 5). This category is composed of 25 upland soil series, e.g. Bang Khla series (Bka), Klaeng series (Kl), Korat series (Kt), Satuk series, Warin series (Wn).

Lastly, soil series occur on the erosion surface and local wash, of which the parent material is transported materials and residuum from clastic rocks or granite. , The soil properties vary greatly depending on parent materials. The soil texture ranges from sand to clay or clay with rock fragment or laterite, and the soil drainage ranges from well to somewhat excessively drained. The group occupies 20.05% of the total land area or 642,624.14 rai (Table 16). The small patches are sparsely distributed on the eastern upland as displayed in Figure 5. There are 14 soil series found in this category, e.g. Ban Bung series (Bbg), Hup Kapong series (Hg), Krabin Buri series (Kb), Tha Yang (Ty).

In addition to the 4 soil categories, there are also the slope complex and other land uses (e.g. residential areas, ponds, canals, reservoirs) occupying 4.04 and 0.10% of the total land area, respectively (Table 16).

Overall, lowland soil series found on tidal flat or former tidal flat, occupying more than 35% of the total area, are found mainly in western part of Chachoengsao province, including Bang Nam Priao, Mueang Chachoengsao, Bang Pakong, Plaeng Yao, Bang Khla, Khlong Khuean, Ban Pho and Ratchasan districts (Figure 5). On the other hand, upland soil series preferentially occur on alluvial terrace and fan complex or erosion surface and local wash. They are scattered throughout the eastern part, including Tha Takiap, Sanam Chai Khet and Phanom Sarakham districts, and occupy more than 50% of the total area (Figure 5). The main upland soil series are Bang Khla series, Krabin Buri series, Lat Ya series, Pang Rai series, and Ko Khanun series, occupying 11.02, 9.38, 5.78, 5.73 and 4.92% of the total land area, respectively (Table 16).

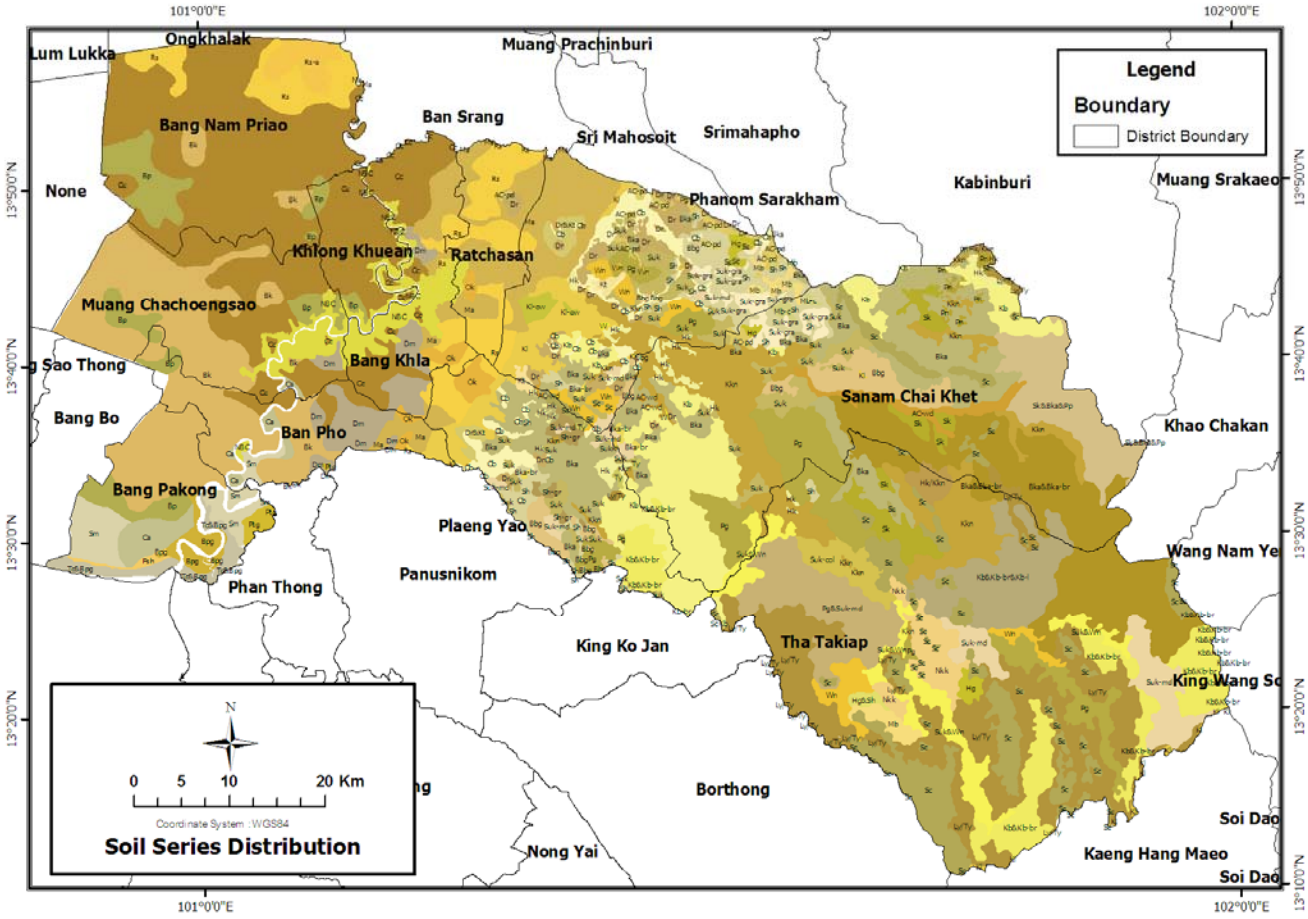


Figure 4 Distribution of soil series in Chachoengsao province

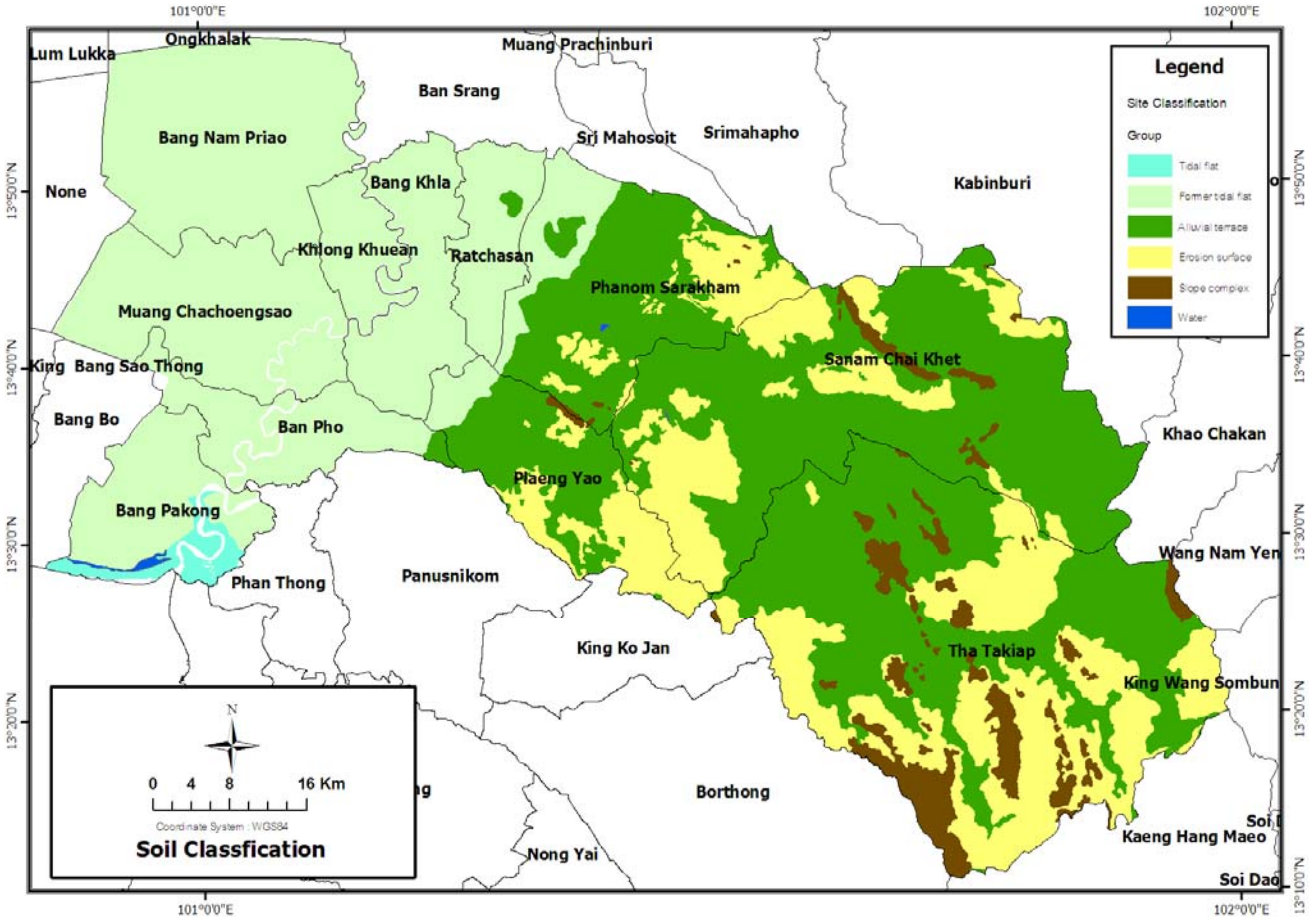


Figure 5 Classification of soil series based on soil geology and parent materials in Chachoengsao province.

Table 16 List of soil series in Chachoengsao province

Soil classification	Area		Coverage percentage
	(ha)	(rai)	
Tidal flat	**4,785.20**	**29,907.52**	**0.93**
Bang Pakong series (Bpg)	1,854.35	11,589.67	0.36
Tha Chin and Bang Pakong series (Tc&Bpg)	2,930.86	18,317.85	0.57
Former tidal flat	**185,939.88**	**1,162,124.22**	**36.26**
Bang Nam Priao series (Bp)	11,613.45	72,584.04	2.26
Bangkok series (Bk)	37,732.30	235,826.87	7.36
Cha-am series (Ca)	3,534.65	22,091.54	0.69
Chachoengsao series (Cc)	65,875.92	411,724.50	12.85
Don Mueang series (Dm)	7,472.60	46,703.77	1.46
Maha Pho series (Ma)	19,368.57	121,053.56	3.78
Ongkharak series (Ok)	2,756.88	17,230.49	0.54
Phan Thong series (Ptg)	842.45	5,265.29	0.16
Rangsit series (Rs)	17,768.18	111,051.12	3.47
Rangsit, very, acid phase (Rs-a)	2,899.86	18,124.15	0.57

Table 16 (Continued)

Soil classification	Area		Coverage percentage
	(ha)	(rai)	
Samut Prakan series (Sm)	5,527.11	34,544.41	1.08
Undifferentiated ridged acid soils (NBC)	10,547.92	65,924.49	2.06
Alluvial terrace and fan complex	**197,968.34**	**1,237,302.13**	**38.61**
Alluvial soils well drained complex (AC-wd)	2,622.47	16,390.45	0.51
Alluvial soils, poorly drained complex (AC-pd)	2,113.45	13,209.09	0.41
Bang Khla series (Bka)	27,536.72	172,104.48	5.37
Bang Khla, brown variant (Bka-br)	348.88	2,180.48	0.07
Bang Khla and Bang Khla, brown soils (Bka&Bka-br)	28,624.36	178,902.24	5.58
Chon Buri series (Cb)	6,804.03	42,525.19	1.33
Don Rai series (Dr)	5,182.94	32,393.38	1.01
Don Rai and Korat soils (Dr&Kt)	1,483.41	9,271.30	0.29
Hin Kong series (Hk)	2,641.25	16,507.83	0.52
Hin Kong / Ko Khanun association (Hk/Kkn)	1,486.19	9,288.67	0.29
Klaeng series (Kl)	8,058.65	50,366.57	1.57
Klaeng, overwash phase (Kl-ow)	992.88	6,205.52	0.19

Table 16 (Continued)

Soil classification	Area		Coverage percentage
	(ha)	(rai)	
Ko Khanun series (Kkn)	25,233.75	157,710.97	4.92
Korat series (Kt)	685.95	4,287.18	0.13
Nong Khok series (Nkk)	4,434.23	27,713.92	0.86
Pang Rai series (Pg)	18,193.14	113,707.14	3.55
Pang Rai and Satuk, moderate soils (Pg&Suk-md)	11,156.83	69,730.20	2.18
Phen series (Pn)	792.08	4,950.48	0.15
Sakon series (Sk)	5,170.26	32,314.10	1.01
Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)	10,399.94	64,999.63	2.03
Satuk series (Suk)	9,303.77	58,148.55	1.81
Satuk and Warin soils (Suk&Wn)	8,146.71	50,916.94	1.59
Satuk, coarse loamy variant (Suk-col)	3,072.56	19,203.48	0.60
Satuk, moderately deep variant (Suk-md)	8,056.61	50,353.84	1.57
Warin series (Wn)	5,427.28	33,920.49	1.06
Erosion surface and local wash	**102,819.86**	**642,624.14**	**20.05**
Ban Bueng series (Bbg)	6,835.80	42,723.74	1.33

Table 16 (Continued)

Soil classification	Area		Coverage percentage
	(ha)	(rai)	
Hup Kapong series (Hg)	1,408.63	8,803.93	0.27
Hup Kapong and Sattahip soil (Hg&Sh)	491.61	3,072.58	0.10
Kabin Buri series (Kb)	22,379.18	139,869.89	4.36
Kabin Buri , brown variant (Kb-br)	3.49	21.82	0.00
Kabin Buri and Kabin Buri, brown soils (Kb&Kb-br)	14,571.51	91,071.91	2.84
Kabin Buri and Kabin Buri, brown variant and Kabin Buri , loamy variant soils (Kb&Kb-br&Kb-l)	11,158.80	69,742.50	2.18
Lat Ya/Tha Yang association (Ly/Ty)	29,615.66	185,097.87	5.78
Map Bon series (Mb)	2,083.58	13,022.39	0.41
Map Bon, clayey variant (Mb-c)	484.95	3,030.94	0.09
Sattahip series (Sh)	9,346.82	58,417.62	1.82
Sattahip, gravelly variant (Sh-gr)	1,114.23	6,963.94	0.22
Satuk, granite derived variant (Suk-gra)	3,046.27	19,039.17	0.59
Tha Yang series (Ty)	279.34	1,745.85	0.05

Table 16 (Continued)

Soil classification	Area		Coverage percentage
	(ha)	(ha)	
Slope complex	**20,722.25**	**129,514.09**	**4.04**
Slope Complex (Sc)	20,722.25	129,514.09	4.04
Other land use	**530.43**	**3,315.16**	**0.10**
River, canal , lake or pond , intermittent pond and wet spot (W)	470.49	2,940.57	0.09
Fish and shrimp ponds - and salt pans (Fsh)	59.93	374.59	0.01
Total	**512,765.96**	**3,204,787.25**	**100.00**

Based on the LDD criteria (Soil Survey and Classification Division, 2000), the total 53 soil series were classified into 3 soil suitability classes for eucalypt planting, i.e. soil suitability class I (suitable for eucalypt planting), soil suitability class II (fairly unsuitable for eucalypt planting), and soil suitability class III (unsuitable for eucalypt planting), based on general soil characteristics of soil series groups. The soil suitability class I was commonly found in upland soil series groups (25-56), well to moderately drained, while the suitability classes II and III were fallen into the lowland ones (1-25, 57-59). The slope complex with slope higher than 35% (Soil Series Group 62) was generally classified as the unsuitable soil. In the present study, soil suitability map for eucalypt planting was then produced to classify soil suitability of each soil series with reference to suitability class of soil series group. For example, Kabin Buri series (Kb), a soil series in the soil series group 46, was classified into the soil suitability class I in accordance with the soil suitability class of the soil series group 46.

The result showed that 28 soil series, occupying about 46% of the total area of Chachoengsao province, were classified to be suitable for eucalypt cultivation (soil suitability class I), while 15 and 10 soil series were categorized into soil suitability class II (fairly unsuitable) and class III (unsuitable), occupying about 18 and 35% of the total area, respectively (Table 17).

Soil suitability class I comprises 28 soil series, 13 of which occur on the alluvial terrace and fan complex and 15 of which occur on erosion surface and local wash categories. The soils are moderately to well drained and mostly found in the eastern part of Chachoengsao province (Table 18, Figure 6).

Soil suitability class II consists of 6 lowland and 9 upland soil series found on former tidal flat and erosion surface and local wash respectively. The former is poorly to very poorly drained soils, while the latter is well to somewhat excessively drained soils. Consequently, existing eucalypt plantations were observed and sampling plots were undertaken in all soil series of the latter group despite of fairly unsuitable soils.

Soil suitability class III is composed of 10 lowland soil series, poorly to very poorly drained soils. There are 2 soil series found on tidal flat and 6 soil series on former tidal flat. In addition, there are other 2 lowland soil series, Klaeng series (Kl) and Klaeng, overwash phase (Kl-ow), loam to loamy clay and poorly drained, occurring on alluvial terrace and fan complex.

As previously mentioned, the slope complex, slope higher than 35% in protected forests, and other land uses, e.g. residential areas, water boundaries, were also classified as unsuitable areas for eucalypt plantation (Table 18, Figure 6). Eucalypt plantations in Chachoengsao province were observed mainly on soil suitability class I and partly on soil suitability class II, classified as suitable and fairly unsuitable areas, respectively. Growth and yield of eucalypt planted on these soils was also analyzed and site quality index was classified accordingly as discussed in the following section.

Table 17 Summary of soil suitability classification for eucalypt planting in Chachoengsao province

Soil suitability class	No. of soil series	Area		Coverage percentage
		(ha)	(rai)	
I: suitable	28	238,037.39	1,487,733.67	46.42
II: fairly unsuitable	15	95,987.17	599,919.82	18.72
III: unsuitable	10	178,741.40	1,117,133.76	34.86
Total	53	512,765.96	3,204,787.25	100.00

Remarks Area of soil suitability class III including the area of slope complex and miscellaneous land uses e.g. residential areas, rivers, ponds, canals.

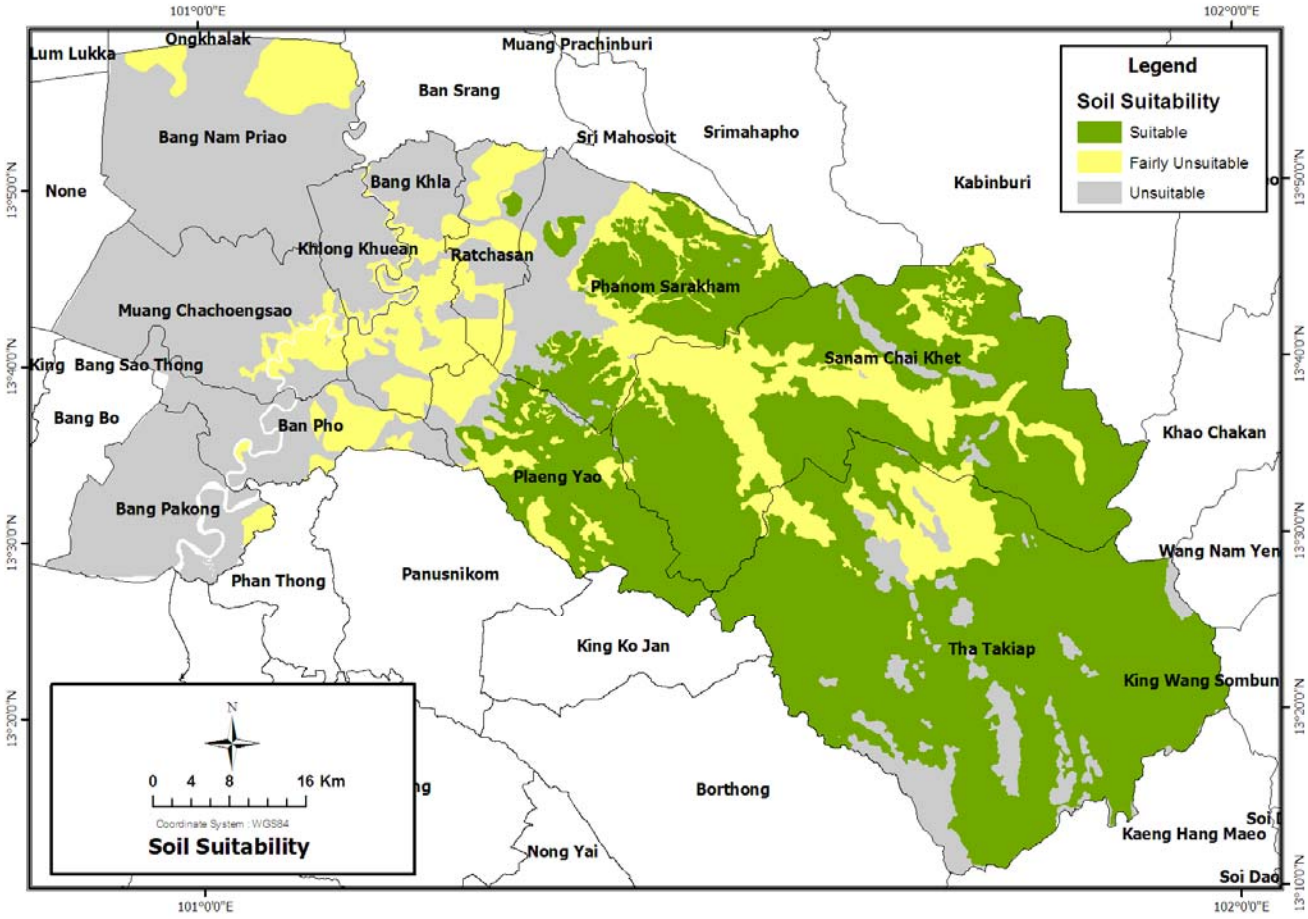


Figure 6 Classification of soil suitability for eucalypt planting in Chachoengsao province.

Table 18 Classification of soil suitability for eucalypt planting in Chachoengsao province

Soil suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
I	**Alluvial terrace and fan complex**	**142,053.32**	**887,833.27**	**27.70**
(suitable)	Bang Khla series (Bka)	27,536.72	172,104.48	5.37
	Bang Khla and Bangkhla, brown soils (Bka&Bka-br)	28,624.36	178,902.24	5.58
	Bang Khla, brown variant (Bka-br)	348.88	2,180.48	0.07
	Don Rai series (Dr)	5,182.94	32,393.38	1.01
	Don Rai and Korat soils (Dr&Kt)	1,483.41	9,271.30	0.29
	Korat series (Kt)	685.95	4,287.18	0.13
	Nong Khok series (Nkk)	4,434.23	27,713.92	0.86
	Pang Rai series (Pg)	18,193.14	113,707.14	3.55
	Pang Rai and Satuk, moderate (Pg&Suk-md)	11,156.83	69,730.20	2.18
	Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)	10,399.94	64,999.63	2.03
	Satuk series (Suk)	9,303.77	58,148.55	1.81
	Satuk and Warin soils (Suk&Wn)	8,146.71	50,916.94	1.59
	Satuk, coarse loamy variant (Suk-col)	3,072.56	19,203.48	0.60
	Satuk, moderately deep variant (Suk-md)	8,056.61	50,353.84	1.57

Table 18 (Continued)

Soil suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Warin series (Wn)	5,427.28	33,920.49	1.06
	Erosion surface and local wash	**95,984.06**	**599,900.40**	**18.72**
	Hup Kapong series (Hg)	1,408.63	8,803.93	0.27
	Hup Kapong and Sattahip soil (Hg&Sh)	491.61	3,072.58	0.10
	Kabin Buri series (Kb)	22,379.18	139,869.89	4.36
	Kabinburi and kabinburi, brown soils (Kb&Kb-br)	14,571.51	91,071.91	2.84
	Kabinburi and kabinburi, brown soils (Kb&Kb-br&Kb-l)	11,158.80	69,742.50	2.18
	Kabin Buri , brown variant (Kb-br)	3.49	21.82	0.00
	Lat Ya/Tha Yang association (Ly/Ty)	29,615.66	185,097.87	5.78
	Map Bon series (Mb)	2,083.58	13,022.39	0.41
	Map Bon, clayey variant (Mb-c)	484.95	3,030.94	0.09
	Sattahip series (Sh)	9,346.82	58,417.62	1.82
	Sattahip, gravelly variant (Sh-gr)	1,114.23	6,963.94	0.22
	Satuk, granite derived variant (Suk-gra)	3,046.27	19,039.17	0.59
	Tha Yang (Ty)	279.34	1,745.85	0.05

Table 18 (Continued)

Soil suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
II	**Former tidal flat**	**42,287.89**	**264,299.31**	**8.25**
(fairly unsuitable)	Don Mueang series (Dm)	7,472.60	46,703.77	1.46
	Undifferentiated ridged acid soils (NBC)	10,547.92	65,924.49	2.06
	Ongkharak series (Ok)	2,756.88	17,230.49	0.54
	Phan Thong series (Ptg)	842.45	5,265.29	0.16
	Rangsit series (Rs)	17,768.18	111,051.12	3.47
	Rangsit, very acid phase (Rs-a)	2,899.86	18,124.15	0.57
	Alluvial terrace and fan complex	**46,863.48**	**292,896.77**	**9.14**
	Alluvial soils, poorly drained complex (AC-pd)	2,113.45	13,209.09	0.41
	Alluvial soils well drained complex (AC-wd)	2,622.47	16,390.45	0.51
	Chon Buri series (Cb)	6,804.03	42,525.19	1.33
	Hin Kong series (Hk)	2,641.25	16,507.83	0.52
	Hin Kong/Ko Khanun association (Hk/Kkn)	1,486.19	9,288.67	0.29
	Ko Khanun series (Kkn)	25,233.75	157,710.97	4.92
	Phen series (Pn)	792.08	4,950.48	0.15

Table 18 (Continued)

Soil suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Sakon series (Sk)	5,170.26	32,314.10	1.01
	Erosion surface and local wash	**6,835.80**	**42,723.74**	**1.33**
	Ban Bung series (Bbg)	6,835.80	42,723.74	1.33
III (unsuitable)	**Tidal flat**	**4,785.20**	**29,907.52**	**0.93**
	Bang Pakong series (Bpg)	1,854.35	11,589.67	0.36
	Tha Chin and Bang Pakong series (Tc&Bpg)	2,930.86	18,317.85	0.57
	Former tidal flat	**143,651.99**	**897,824.91**	**28.02**
	Bangkok series (Bk)	37,732.30	235,826.87	7.36
	Bang Nam Priao series (Bp)	11,613.45	72,584.04	2.26
	Cha-am series (Ca)	3,534.65	22,091.54	0.69
	Chachoengsao series (Cc)	65,875.92	411,724.50	12.85
	Maha Pho series (Ma)	19,368.57	121,053.56	3.78
	Samut Prakan series (Sm)	5,527.11	34,544.41	1.08

Table 18 (Continued)

Soil suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Alluvial terrace and fan complex	**9,051.53**	**56,572.09**	**1.77**
	Klaeng series (Kl)	8,058.65	50,366.57	1.57
	Klaeng, overwash phase (Kl-ow)	992.88	6,205.52	0.19
	Slope complex	**20,722.25**	**129,514.09**	**4.04**
	Slope Complex (Sc)	20,722.25	129,514.09	4.04
	Other land uses	**530.43**	**3,315.16**	**0.10**
	Other land uses (River, Canal, Lake or Pond) (W, Fsh)	530.43	3,315.16	0.10
	Total	**512,765.96**	**3,204,787.25**	**100.00**

Growth and yield analysis

Growth (DBH and height) and yield (biomass and fresh weight) of eucalypt seedling stand was summarized in each soil series suitable and fairly unsuitable for eucalypt planting in Chachoensao province (Table 19). Overall, the variations in growth and yield of eucalypt planted on different soil series were relatively similar in younger stands but more pronounced when plantations became older, particularly at 5 years old.

DBH and heights of eucalypt plantation observed in the Sattahip series (Sh), Ban Bung series (Bbg), and Pang Rai series (Pg) as well as Satuk moderately deep variant (Suk-md) was generally greater in most age classes. The greatest eucalypt DBH values at 2-3 years old was found in Alluvial soils poorly drained complex (AC-pd), while those at 4 and 5 years old were obtained in Sh and Bbg. The average DBH values at 2-5 years of age were 8.09, 9.47, 10.31 and 12.34 cm, respectively. Similarly, the greatest eucalypt heights at 2-3 and 4-5 years old were observed in AC-pd and Suk-md, with average heights at 2-5 years old of 10.57, 13.33, 16.44 and 16.32 m, respectively (Table 19).

In accordance with diameter and height growth, aboveground biomass and economic production (stem fresh weight) of eucalypt plantations observed in Sh, Bbg, Pg and Suk-md was generally greater than that of others, but large variation within each soil series was also evident (Table 19). For eucalypt plantations at 2-5 years old, the maximum yield with aboveground biomass values of 34.08, 56.68, 83.69 and 124.22 t ha^{-1} or 5.45, 9.07, 13.39 and 19.87 t rai^{-1} and stem fresh weight values of 72.02, 120.65, 172.93 and 242.97 t ha^{-1} or 11.02, 19.30, 27.67 and 38.87 t rai^{-1} were determined in AC-pd, AC-pd, Sh and Bbg, respectively. Interestingly, AC-pd, poorly drained soils fairly unsuitable for eucalypt planting, yielded greater plantation production in early ages, but only a small number of sampling plots was observed. In addition, the existing older plantations in this soil series were not available to provide sufficient data for a concrete conclusion in the current study.

Table 19 Diameter at breast height (DBH), height, stem biomass (W_s), branch biomass (W_b), leaf biomass (W_l) and economic production (stem fresh weight) of eucalypt plantations observed in different soil series in Chachoengsao province

Soil series	Age (yr)	n	DBH (cm)	Height (m)	Biomass (t ha^{-1})			Aboveground biomass		Economic production	
					W_s	W_b	W_l	(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Soil suitability class I: suitable											
Bang Khla series (Bka)	2	7	7.50±0.17	10.53±0.45	22.10±0.13	2.99±0.02	4.12±0.02	29.21±0.17	4.67±0.03	61.86±0.36	9.90±0.06
	3	9	8.47±0.28	11.91±0.66	33.87±0.43	4.82±0.06	3.46±0.03	42.15±0.52	6.74±0.08	89.18±1.13	14.27±0.18
	4	7	8.90±0.37	12.55±0.72	46.84±1.92	4.00±0.09	1.32±0.03	52.16±2.04	8.35±0.33	106.31±4.30	17.01±0.69
	5	4	9.43±0.26	14.59±0.68	61.32±0.92	4.61±0.04	1.55±0.01	67.48±0.97	10.80±0.16	138.63±2.05	22.18±0.33
Bang Khla and Bang	2	10	7.08±0.33	10.51±0.68	18.75±1.47	2.44±0.24	3.61±0.23	24.79±1.93	3.97±0.31	52.58±4.06	8.41±0.65
Khla, brown soils	3	10	8.19±0.23	12.02±0.30	32.25±1.39	4.60±0.19	3.34±0.10	40.19±1.68	6.43±0.27	84.95±3.63	13.59±0.58
(Bka&Bka-br)	4	5	9.00±0.50	13.03±0.34	50.01±6.64	4.13±0.28	1.37±0.10	55.51±7.03	8.88±1.12	113.38±14.82	18.14±2.37
	5	3	9.83±0.75	15.29±0.49	70.11±8.54	4.94±0.32	1.67±0.12	76.71±8.98	12.27±1.44	158.16±18.99	25.31±3.04
Bang Khla, brown variant	2	6	7.51±0.31	10.12±0.66	21.45±2.78	2.88±0.46	4.02±0.42	28.35±3.67	4.54±0.59	60.05±7.69	9.61±1.23
(Bka-br)	3	7	8.44±0.57	11.70±1.35	34.82±6.79	4.95±0.93	3.51±0.49	43.28±8.21	6.92±1.31	91.65±17.73	14.66±2.84
	4	1	9.42±0.00	12.59±0.00	52.83±0.00	4.26±0.00	1.42±0.00	58.51±0.00	9.36±0.00	119.70±0.00	19.15±0.00
Don Rai series (Dr)	2	3	7.75±0.36	10.90±0.34	24.22±1.70	3.35±0.29	4.44±0.25	32.01±2.25	5.12±0.36	67.70±4.71	10.83±0.75
	3	7	8.41±0.73	11.60±0.97	33.06±6.68	4.71±0.92	3.39±0.48	41.16±8.08	6.58±1.29	87.06±17.44	13.93±2.79
	4	4	10.01±0.39	14.40±1.59	68.61±9.96	4.88±0.38	1.65±0.14	75.13±10.48	12.02±1.68	154.83±22.17	24.77±3.55
Kabin Buri series (Kb)	2	5	7.25±0.12	9.43±0.30	18.76±0.57	2.44±0.09	3.61±0.09	24.81±0.75	3.97±0.12	52.62±1.57	8.42±0.25
	3	5	8.54±0.18	11.52±0.32	33.47±0.50	4.76±0.07	3.43±0.04	41.66±0.60	6.67±0.10	88.13±1.30	14.10±0.21
	4	8	9.43±0.45	13.45±0.91	56.86±8.40	4.42±0.34	1.48±0.13	62.75±8.87	10.04±1.42	128.66±18.73	20.59±3.00

Table 19 (Continued)

Soil series	Age (yr)	n	DBH (cm)	Height (m)	Biomass (t ha^{-1})			Aboveground biomass		Economic production	
					W_s	W_b	W_l	(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Lat Ya / Tha Yang	2	5	7.58±0.21	9.65±0.45	20.82±1.07	2.77±0.18	3.93±0.16	27.52±1.41	4.40±0.23	58.31±2.96	9.33±0.47
association (Ly/Ty)	3	5	8.60±0.17	11.73±0.62	34.36±0.66	4.89±0.09	3.49±0.05	42.74±0.80	6.84±0.13	90.46±1.72	14.47±0.28
	4	3	9.20±0.19	13.80±0.36	55.25±2.04	4.36±0.08	1.46±0.03	61.07±2.16	9.77±0.34	125.09±4.55	20.01±0.73
Pang Rai series (Pg)	2	6	7.31±0.25	9.86±0.60	19.80±0.41	2.60±0.07	3.77±0.06	26.17±0.55	4.19±0.09	55.48±1.15	8.88±0.18
	3	5	8.72±0.25	12.14±0.52	36.34±0.77	5.16±0.10	3.63±0.05	45.13±0.93	7.22±0.15	95.63±2.00	15.30±0.32
	4	5	9.73±0.28	13.00±0.52	58.15±1.81	4.48±0.07	1.50±0.03	64.13±1.91	10.26±0.30	131.56±4.03	21.05±0.64
	5	6	10.73±0.28	14.48±1.16	79.18±7.33	5.26±0.26	1.79±0.10	86.23±7.69	13.80±1.23	178.31±16.27	28.53±2.60
Sattahip series (Sh)	2	3	7.37±0.07	10.30±0.53	21.01±1.28	2.80±0.21	3.96±0.20	27.77±1.69	4.44±0.27	58.83±3.55	9.41±0.57
	3	3	9.46±0.08	13.06±0.74	44.97±2.93	6.33±0.40	4.21±0.19	55.51±3.52	8.88±0.56	118.12±7.63	18.90±1.22
	4	3	10.31±0.33	15.24±1.18	76.75±1.78	5.18±0.06	1.76±0.02	83.69±1.87	13.39±0.30	172.93±3.95	27.67±0.63
	5	4	11.72±0.78	15.62±0.76	102.10±9.15	6.02±0.29	2.08±0.11	110.19±9.54	17.63±1.53	229.06±20.23	36.65±3.24
Sakon and Bang Khla	2	5	6.94±0.24	9.55±0.40	17.49±0.51	2.23±0.08	3.41±0.08	23.13±0.68	3.70±0.11	49.08±1.42	7.85±0.23
and Phon Phisai soils	3	5	8.14±0.15	11.74±0.35	31.23±0.43	4.46±0.06	3.27±0.03	38.96±0.52	6.23±0.08	82.30±1.13	13.17±0.18
(Sk&Bka&Pp)	4	5	8.97±0.24	13.38±0.59	50.82±1.45	4.17±0.06	1.39±0.02	56.38±1.54	9.02±0.25	115.21±3.24	18.43±0.52
	5	1	10.03±0.00	16.31±0.00	77.94±0.00	5.22±0.00	1.78±0.00	84.94±0.00	13.59±0.00	175.57±0.00	28.09±0.00
Satuk series (Suk)	2	5	7.29±0.21	10.28±0.58	20.51±0.28	2.72±0.05	3.88±0.04	27.11±0.37	4.34±0.06	57.46±0.77	9.19±0.12
	3	5	8.65±0.18	12.11±0.56	35.76±0.40	5.08±0.05	3.59±0.03	44.43±0.48	7.11±0.08	94.11±7.04	15.06±1.13
	4	3	9.86±0.29	12.74±0.14	58.55±2.87	4.50±0.12	1.51±0.04	64.56±3.02	10.33±0.48	132.46±6.39	21.19±1.02
	5	8	10.61±1.05	13.96±0.78	75.67±18.11	5.11±0.64	1.74±0.24	82.51±19.00	13.20±3.04	170.46±40.21	27.27±6.43

Table 19 (Continued)

Soil series	Age (yr)	n	DBH (cm)	Height (m)	Biomass (t ha^{-1})			Aboveground biomass		Economic production	
					W_s	W_b	W_l	(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Satuk, granite derived	2	8	7.31±0.89	11.12±1.48	22.73±7.90	3.14±1.39	4.19±1.16	30.06±10.45	4.81±1.67	63.56±21.80	10.17±3.49
variant (Suk-gra)	3	4	8.71±1.63	12.08±3.53	38.95±18.66	5.49±2.57	3.72±1.39	48.16±22.62	7.71±3.62	102.35±48.76	16.38±7.80
	4	5	10.46±0.83	14.68±1.42	76.94±15.71	5.17±0.56	1.76±0.21	83.87±16.48	13.42±2.64	173.32±34.88	27.73±5.58
Satuk, moderately deep	2	3	7.67±0.15	10.37±0.17	22.72±1.09	3.09±0.18	4.22±0.16	30.03±1.44	4.80±0.23	63.57±3.02	10.17±0.48
variant (Suk-md)	3	3	8.59±0.10	12.87±0.26	37.30±0.61	5.29±0.08	3.70±0.04	46.28±0.73	7.41±0.12	98.12±1.59	15.70±0.25
	4	4	9.16±0.25	16.44±0.61	65.43±6.06	4.76±0.23	1.61±0.09	71.80±6.37	11.49±1.02	147.77±13.47	23.64±2.16
	5	6	9.42±0.45	16.32±1.92	68.49±8.23	4.88±0.30	1.65±0.11	75.02±8.65	12.00±1.38	154.58±18.29	24.73±2.93
Tha Yang series (Ty)	2	3	7.61±0.19	10.06±0.30	21.79±1.34	2.94±0.23	4.07±0.20	28.80±1.77	4.61±0.28	61.00±3.70	9.76±0.59
	3	3	8.62±0.23	11.08±0.15	32.86±1.93	4.68±0.26	3.39±0.14	40.93±2.33	6.55±0.37	86.55±5.03	13.85±0.80
Warin series (Wn)	2	5	7.39±0.11	9.79±0.30	20.10±0.35	2.65±0.06	3.82±0.05	26.56±0.46	4.25±0.07	56.31±0.98	9.01±0.16
	3	5	8.18±0.06	12.42±0.09	33.16±0.35	4.72±0.05	3.41±0.03	41.29±0.42	6.61±0.07	87.34±0.92	13.97±0.15
	4	3	10.07±0.01	12.51±0.11	60.02±0.38	4.56±0.02	1.53±0.01	66.10±0.40	10.58±0.06	135.72±0.85	21.71±0.14
	5	3	10.70±0.32	14.62±1.67	79.31±8.24	5.27±0.29	1.79±0.11	86.37±8.64	13.82±1.38	178.61±18.28	28.58±2.93
Soil suitability class II: fairly unsuitable											
Alluvial soils, poorly	2	3	8.09±0.52	10.57±1.19	25.79±5.45	3.64±0.94	4.66±0.81	34.08±7.20	5.45±1.15	72.02±15.06	11.52±2.41
drained complex	3	1	9.47±0.00	13.33±0.00	45.94±0.00	6.46±0.00	4.28±0.00	56.68±0.00	9.07±0.00	120.65±0.00	19.30±0.00
(AC-pd)											
Alluvial soils well	2	4	6.37±0.09	10.41±0.69	16.09±1.30	2.01±0.20	3.19±0.21	21.29±1.71	3.41±0.27	45.20±3.61	7.23±0.58
drained complex	3	3	8.01±0.13	13.02±0.03	33.28±1.02	4.74±0.14	3.42±0.07	41.44±1.24	6.63±0.20	87.64±2.67	14.02±0.43
(AC-wd)											

Table 19 (Continued)

Soil series	Age (yr)	n	DBH (cm)	Height (m)	Biomass (t ha^{-1})			Aboveground biomass		Economic production	
					W_s	W_b	W_l	(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Ban Bueng series (Bbg)	2	5	7.04±0.52	9.69±1.56	19.74±3.07	2.60±0.48	3.75±0.49	26.09±4.05	4.17±0.65	55.30±8.52	8.85±1.36
	3	5	8.26±0.29	12.85±1.09	34.65±0.52	4.93±0.07	3.51±0.04	43.09±0.63	6.89±0.10	91.22±1.37	14.60±0.22
	4	4	10.27±1.09	13.36±1.38	67.74±18.08	4.82±0.69	1.63±0.25	74.19±19.02	11.87±3.04	152.85±40.21	24.46±6.43
	5	4	12.34±0.03	15.02±0.26	109.92±2.24	10.69±0.18	3.61±0.07	124.22±2.49	19.87±0.40	242.97±5.14	38.87±0.82
Chon Buri series (Cb)	2	1	6.88±0.00	8.96±0.00	16.27±0.00	2.04±0.00	3.22±0.00	21.53±0.00	3.44±0.00	45.71±0.00	7.31±0.00
	3	3	7.48±0.03	8.98±0.01	21.12±0.12	3.06±0.02	2.49±0.01	26.67±0.15	4.27±0.02	55.83±0.33	8.93±0.05
Hin Kong series (Hk)	2	5	7.53±0.07	9.64±0.38	20.53±0.51	2.73±0.08	3.88±0.08	27.14±0.67	4.34±0.11	57.52±1.40	9.20±0.22
	3	5	8.27±0.26	11.89±0.45	32.46±1.24	4.63±0.17	3.36±0.09	40.44±1.50	6.47±0.24	85.50±3.24	13.68±0.52
	4	4	9.58±0.85	13.09±0.94	57.68±14.38	4.44±0.57	1.49±0.21	63.60±15.16	10.18±2.43	130.47±32.03	20.88±5.13
	5	5	10.09±0.85	13.74±0.90	67.03±14.57	4.81±0.54	1.62±0.20	73.46±15.31	11.75±2.45	151.29±32.38	24.21±5.18
Hin Kong/Ko Khanun association (Hk/Kkn)	2	6	6.59±0.31	9.56±1.03	16.04±3.05	2.01±0.49	3.17±0.48	21.23±4.02	3.40±0.64	45.06±8.45	7.21±1.35
	3	3	7.90±0.46	11.32±0.49	28.63±2.67	4.10±0.37	3.07±0.20	35.80±3.24	5.73±0.52	75.49±6.99	12.08±1.12
	4	5	8.38±0.17	12.96±0.22	42.91±2.42	3.82±0.11	1.26±0.04	47.98±2.57	7.68±0.41	97.51±5.41	15.60±0.87
	5	3	8.96±0.06	15.71±0.23	59.66±1.68	4.54±0.07	1.52±0.02	65.73±1.78	10.52±0.28	134.94±3.75	21.59±0.60
Ko Khanun series (Kkn)	2	3	7.83±0.27	9.88±0.60	22.55±0.94	3.06±0.16	4.19±0.14	29.80±1.24	4.77±0.20	63.09±2.59	10.09±0.41
	3	3	8.63±0.16	12.41±0.44	36.41±1.02	5.17±0.14	3.64±0.07	45.21±1.23	7.23±0.20	95.81±2.67	15.33±0.43
	4	3	9.30±0.09	13.99±0.20	57.20±1.13	4.44±0.05	1.49±0.02	63.13±1.19	10.10±0.19	129.45±2.51	20.71±0.40
Phen series (Pn)	2	3	7.09±0.27	9.20±0.63	17.56±0.58	2.24±0.09	3.42±0.09	23.22±0.76	3.72±0.12	49.28±1.61	7.88±0.26
	3	3	8.39±0.23	11.90±0.39	33.33±0.68	4.75±0.09	3.42±0.05	41.50±0.82	6.64±0.13	87.79±1.77	14.05±0.28
	4	3	9.45±0.25	13.40±0.71	56.52±0.75	4.41±0.08	1.46±0.03	62.40±1.95	9.98±0.31	125.98±4.12	20.16±0.66

Table 19 (Continued)

Soil series	Age (yr)	n	DBH (cm)	Height (m)	Biomass (t ha^{-1})			Aboveground biomass		Economic production	
					W_s	W_b	W_l	(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Sakon series (Sk)	2	2	6.25±0.43	10.31±0.04	16.02±1.58	2.00±0.24	3.17±0.26	21.20±2.08	3.39±0.33	45.01±4.40	7.20±0.70
	3	2	7.87±0.07	11.56±0.55	29.01±1.72	4.15±0.24	3.10±0.13	36.27±2.08	5.80±0.33	76.50±4.49	12.24±0.72

Site suitability classification

Site quality of all soil series was classified following to an anamorphosis method (Prasomsin, 1991) on the 3-year basis. The scatter diagram of the relationship between age and aboveground biomass per unit area of each soil series and the site index curves classified into 3 levels of site quality, i.e. very good, good and moderate, are presented in Figure 7. The yield of eucalypt plantations in different site quality classes on the 3-year basis are also shown in Table 20. The productivity of eucalypt plantations in form of economic production (stem fresh weight) per unit land area on the very good, good and moderate sites ranged from 110.78-129.20, 92.45-110.78 and 74.13-92.45 t ha^{-1} or 17.72-20.67, 14.79-17.72 and 11.86-14.79 t rai^{-1}, respectively.

Except for AC-pd, Ko Khanun series (Kkn), and Bbg, all soil series, categorized by LDD criteria (Soil Survey and Classification Division, 2000) as suitable soils for eucalypt planting or soil suitability class I, were classified in the present study as a very good site quality. Similarly, the good site quality was also observed in both suitable and fairly unsuitable soils for eucalypt planting. The only soil series, classified as a moderate site quality, was Chon Buri series (Cb). However, the soil series, classified in soil suitability class I, but the sampling plots were not located, were categorized in accordance with similarity of soil properties. For example, Kabin Buri, brown variant (Kb-br), was categorized as a good site quality following to Kabin Buri series (Kb) (Table 20). Furthermore, the unsuitable sites were mainly soil series categorized by LDD criteria mainly as unsuitable soils and partly as fairly unsuitable soils, where existing eucalypt plantations were not observed. In conclusion, site suitability in the present study can be classified into 4 classes based on site quality index, i.e. very good, good, moderate, and unsuitable sites.

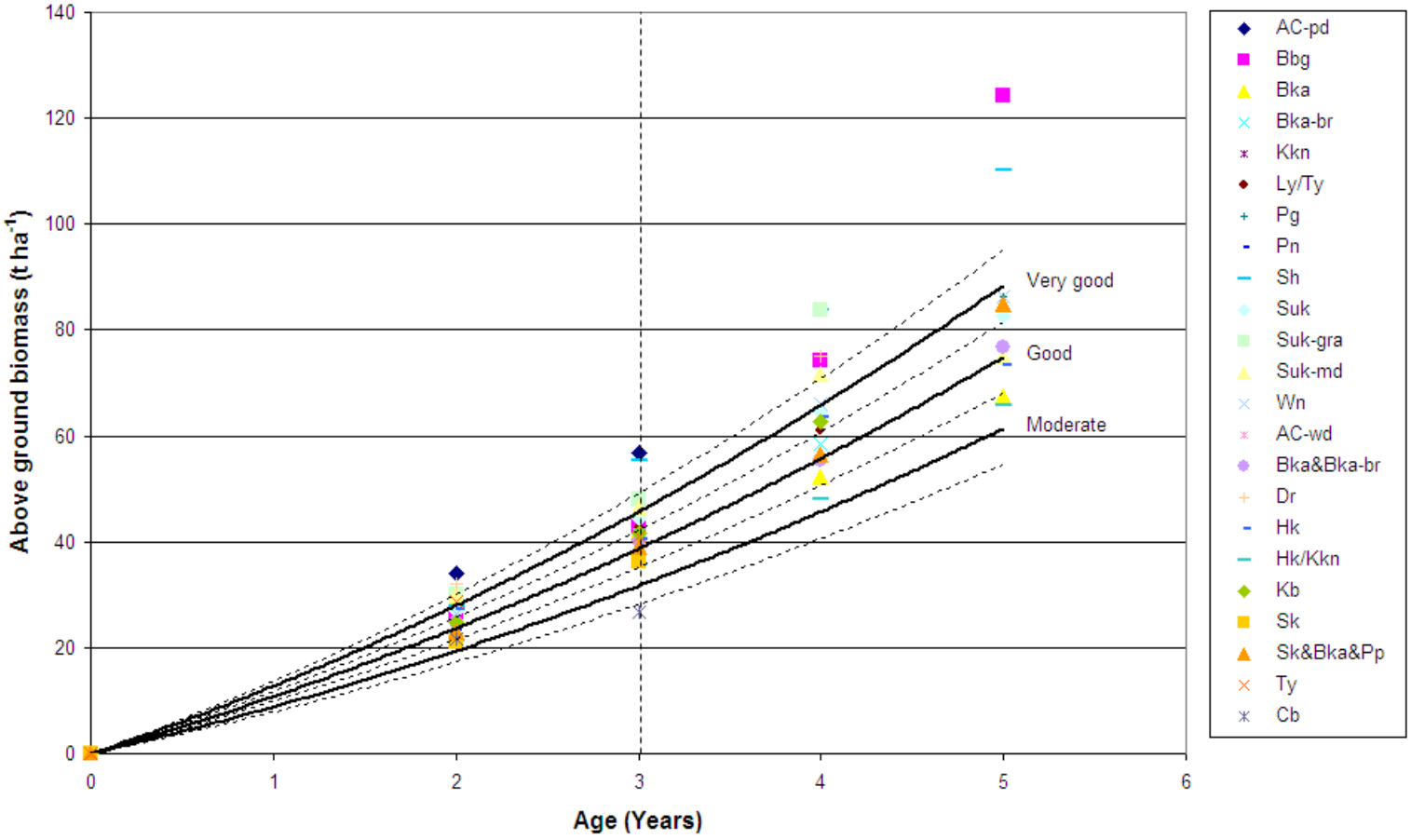


Figure 7 Scatter diagram of the relationship between age and aboveground biomass of different soil series and site index curves of eucalypt plantations in Chachoengsao province.

Table 20 Economic production (stem fresh weight) of eucalypt plantations on different site suitability classes based on the 3-year basis in Chachoengsao province

Site suitability class	Soil series	LDD soil suitability class	Economic production	
			(t ha^{-1})	(t rai^{-1})
Very good	**Alluvial terrace and fan complex**		110.78-129.20	17.72-20.67
	Bang Khla series (Bka)	Suitable		
	Bang Khla, brown variant (Bka-br)	Suitable		
	Pang Rai series (Pg)	Suitable		
	Satuk series (Suk)	Suitable		
	Satuk, granite derived variant (Suk-gra)	Suitable		
	Satuk, moderately deep variant (Suk-md)	Suitable		
	Alluvial soils, poorly drained complex (AC-pd)	Fairly unsuitable		
	Ko Khanun series (Kkn)	Fairly unsuitable		
	Pang Rai and Satuk, moderate soils (Pg&Suk-md)*	Suitable		
	Nong Khok series (Nkk)*	Suitable		
	Satuk, coarse loamy variant (Suk-col)*	Suitable		
	Satuk and Warin soils (Suk&Wn)*	Suitable		
	Erosion surface and local wash			
	Lat Ya / Tha Yang association (Ly/Ty)	Suitable		

Table 20 (Continued)

Site suitability class	Soil series	LDD soil suitability class	Economic production	
			(t ha^{-1})	(t rai^{-1})
	Sattahip series (Sh)	Suitable		
	Ban Bueng series (Bbg)	Fairly unsuitable		
	Hup Kapong and Sattahip soil (Hg&Sh)*	Suitable		
	Map Bon series (Mb)*	Suitable		
	Map Bon, clayey variant (Mb-c)*	Suitable		
	Hup Kapong series (Hg)*	Suitable		
	Sattahip, gravelly variant (Sh-gr)*	Suitable		
Good	**Alluvial terrace and fan complex**		92.45-110.78	14.79-17.72
	Don Rai series (Dr)	Suitable		
	Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)	Suitable		
	Alluvial soils well drained complex (AC-wd)	Fairly unsuitable		
	Hin Kong series (Hk)	Fairly unsuitable		
	Hin Kong / Ko Khanun association (Hk/Kkn)	Fairly unsuitable		
	Phen series (Pn)	Fairly unsuitable		

Table 20 (Continued)

Site suitability class	Soil series	LDD soil suitability class	Economic production	
			(t ha^{-1})	(t rai^{-1})
	Sakon series (Sk)	Fairly unsuitable		
	Warin series (Wn)	Suitable		
	Korat series (Kt)*	Suitable		
	Don Rai and Korat soils (Dr&Kt)*	Suitable		
	Bang Khla and Bangkhla, brown soils (Bka&Bka-br)*	Suitable		
	Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)*	Suitable		
	Erosion surface and local wash			
	Kabin Buri and Kabin Buri, brown soils (Kb&Kb-br)	Suitable		
	Kabin Buri series (Kb)	Suitable		
	Tha Yang (Ty)	Suitable		
	Kabin Buri and Kabin Buri, brown variant and Kabin Buri , loamy variant soils (Kb&Kb-br&Kb-l)*	Suitable		
	Kabin Buri , brown variant (Kb-br)*	Suitable		
Moderate	**Alluvial terrace and fan complex**		74.13-92.45	11.86-14.79
	Chon Buri series (Cb)	Fairly unsuitable		

Remarks * classified by similarity of soil properties

Expectedly, difference in soil/site suitability classification for eucalypt planting between the LDD criteria and the criteria developed in the current study was evident as shown in Table 20. For instance, soil series classified by LDD as fairly unsuitable soil for eucalypt planting, such as AC-pd, Kkn and Bbg, were recognized as very good site quality due to greater plantation yield observed in the sampling plots. The LDD criteria were rather broad and based primarily on general soil characteristics of soil series groups, e.g. soil texture, organic layer, nutrient status, soil drainage, salinity, and the suitable soils were mainly upland soil series group (25-56) in the eastern part of the province (Figure 6).

On the other hand, the criteria developed in the current study were based solely on plantation productivity undertaken in privately-owned plantations in various soil series across a wide range of soil characteristics in Chachoengsao province. The site suitability classified as a very good site quality was observed preferentially on erosion surface and local wash as well as alluvial terrace and fan complex, ranging from sandy loam to sand and moderately to very well drained (Figure 8). The good site quality was also found mainly on alluvial terrace and fan complex and partly on erosion surface and local wash, while the moderate site quality with the lowest productivity was found only on Cb soil series, loam to sandy loam and poorly drained (Table 20). Overall, these three site suitability classes were classified by LDD criteria mainly as suitable and partly as fairly unsuitable soil for eucalypt planting. Furthermore, the unsuitable sites for eucalypt planting in the current study were found mainly on tidal flat, former tidal flat and partly on alluvial terrace and fan complex in the western part of the province. They were mainly categorized by LDD as soil suitability class III and partly as suitability class II, where existing eucalypt plantations were not observed.

However, the yield of eucalypt plantation obtained in the present study was rather high compared to that in other studies. The aboveground biomass of 5-year-old eucalypt plantations in the very good site quality, varying from 81.63 - 95.21 t ha^{-1} (Table 21), was markedly higher than that investigated in different soil groups in northeastern part of Thailand by Insuan (2005), of which the aboveground biomass of

similar age observed for the best site quality was 67.50 t ha^{-1}. The higher productivity could be possibly contributed to the fact that, in the current study, yield estimation was based on growth data undertaken from privately-owned plantations, established with suitable clones well adapted to the site and with intensive plantation management. Furthermore, the plantation yiled was estimated based on a survival rate of 100% (2,500 trees ha^{-1} or 400 trees rai^{-1}). However, the greater production estimated for the very good site, 183.71-214.27 t ha^{-1} of stem fresh weight, was comparatively similar to that reported for the superior 5-year-old eucalypt clone (178 t ha^{-1} of tresh weight) planted on the proper site with 1,250 trees ha^{-1} as reported by Aramsri (1999).

Growth and yield of eucalypt plantation depends not only on soil potential but also on suitable planting materials and plantation management. The study on different eucalypt clones at three different sites in the Northeast pointed out that the productivity could be increased by two folds if suitable clones to the site were chosen (Aramsri, 1999). The finding also suggested that, in order to maximize plantation yields and income per unit area, farmers should plant suitable clones on proper sites. Likewise, plantation management based on appropriate silvicultural practices could help improving plantation productivity. Variation in productivity of eucalypt plantations due to different site managements was extensively reported in many countries (Bouillet *et al*., 2000; Goncalves *et al*., 2000). Low survival rate and high variation in early growth were often observed in poor management plantations, while high survival rate and yield were commonly found in the intensive management ones. About 25% of successful forest plantations in the tropics depend on weed control, especially during the early stage of the planted tree development. Moreover, with an exception of soil/foliar analysis, nutrients leading to vegetative growth promotion should be applied at both the planting time and late rotation of eucalypts (Thaiutsa, 2003).

The obtained potential of soil series, from which growth data were taken, were categorized based on the site quality index as shown in Table 22. Conclusively, 37 soil series, occurring mainly in the eastern part and occupying more than half of the

total area in the province, were recognized as suitable sites for eucalypt planting. In contrast, about 43% of the total land area was categorized as unsuitable sites and found mainly in western part of the province, including Bang Nam Priao, Mueang Chachoengsao, Bang Pakong, Bang Khla, Khlong Khuean, Ban Pho and Ratchasan districts (Figure 8).

Of the 37 soil series suitable for eucalypt planting, 21 soil series occupying almost 35% of the total area were classified as the very good site quality. Such soil series were scattered throughout the eastern part, including Tha Takiap, Sanam Chai Khet, Plaeng Yao and Phanom Sarakham districts (Figure 8). The main soil series in this category were Ly/Ty, Pg, Bka, and Kkn, occupying 5.78, 5.73, 5.44 and 4.92% of the total land area, respectively (Table 23). Similarly, there were 15 soil series categorized as the good site quality for eucalypt planting. They were found preferentially in the eastern part, occupying about 21% of the total area (Table 22 and Figure 8). Kabin Buri series (Kb) and Bang Khla and Bang Khla, brown soils series (Bka&Bka-br) are the main soils in this category, occupying 9.38 and 5.58% of the total land area, respectively (Table 23). Only the Chon Buri series (Cb) soil series, sparsely scattered between lowland and upland soils, was classified into moderate site quality class and occupied only 1.33% of the total land area (Table 23 and Figure 8).

Table 21 Estimated yield of eucalypt plantations on different site suitability classes in Chachoengsao province

Site suitability class	Age (years)	Above ground biomass		Economic production	
		(t ha^{-1})	(t rai^{-1})	(t ha^{-1})	(t rai^{-1})
Very good	2	25.89 – 30.20	4.14 - 4.83	72.52 - 84.59	11.60 - 13.53
	3	42.08 – 49.08	6.73 - 7.85	110.78 - 129.20	17.72 - 20.67
	4	60.72 – 70.82	9.72 - 11.33	137.25 - 160.09	21.96 - 25.61
	5	81.63 – 95.21	13.06 - 15.23	183.71 - 214.27	29.39 - 34.28
Good	2	21.61 – 25.89	3.46 - 4.14	60.53 - 72.52	9.68 - 11.60
	3	35.12 – 42.08	5.62 - 6.73	92.45 - 110.78	14.79 - 17.72
	4	50.68 – 60.72	8.11 - 9.72	114.55 - 137.25	18.33 - 21.96
	5	68.13 – 81.63	10.90 - 13.06	153.33 - 183.71	24.53 - 29.39
Moderate	2	17.33 – 21.61	2.77 - 3.46	48.53 - 60.53	7.77 - 9.68
	3	28.16 – 35.12	4.51 - 5.62	74.13 - 92.45	11.86 - 14.79
	4	40.64 – 50.68	6.50 - 8.11	91.85 - 114.55	14.70 - 18.33
	5	54.63 – 68.13	8.74 - 10.90	122.94 - 153.33	19.67 - 24.53

The site potential, may not be a complete indicator for growth and yield of eucalypt plantations. In the current study, the sampling plots were taken from privately-owned plantations with different clones and management regimes. Practically, such plantations were established with genetically-improved materials well adapted to the site and with intensive plantation management. Nevertheless, estimation of growth of eucalypt plantation based on the site quality index could be used to represent the yield potential as data input for DSS for eucalypt plantation investment in the study area.

Table 22 Summary of site suitability for eucalypt planting in Chachoengsao province

Site suitability class	No. of soil series	Area		Coverage percentage
		(ha)	(rai)	
Very good	21	177,451.48	1,109,071.75	34.61
Good	15	107,481.16	671,757.24	20.96
Moderate	1	6,804.03	42,525.19	1.33
Unsuitable	16	221,029.29	1,381,433.07	43.11
Total	53	512,765.96	3,204,787.25	100.00

Remarks Area of unsuitable site including the area of slope complex and miscellaneous land uses e.g. residential areas, rivers, ponds, canals

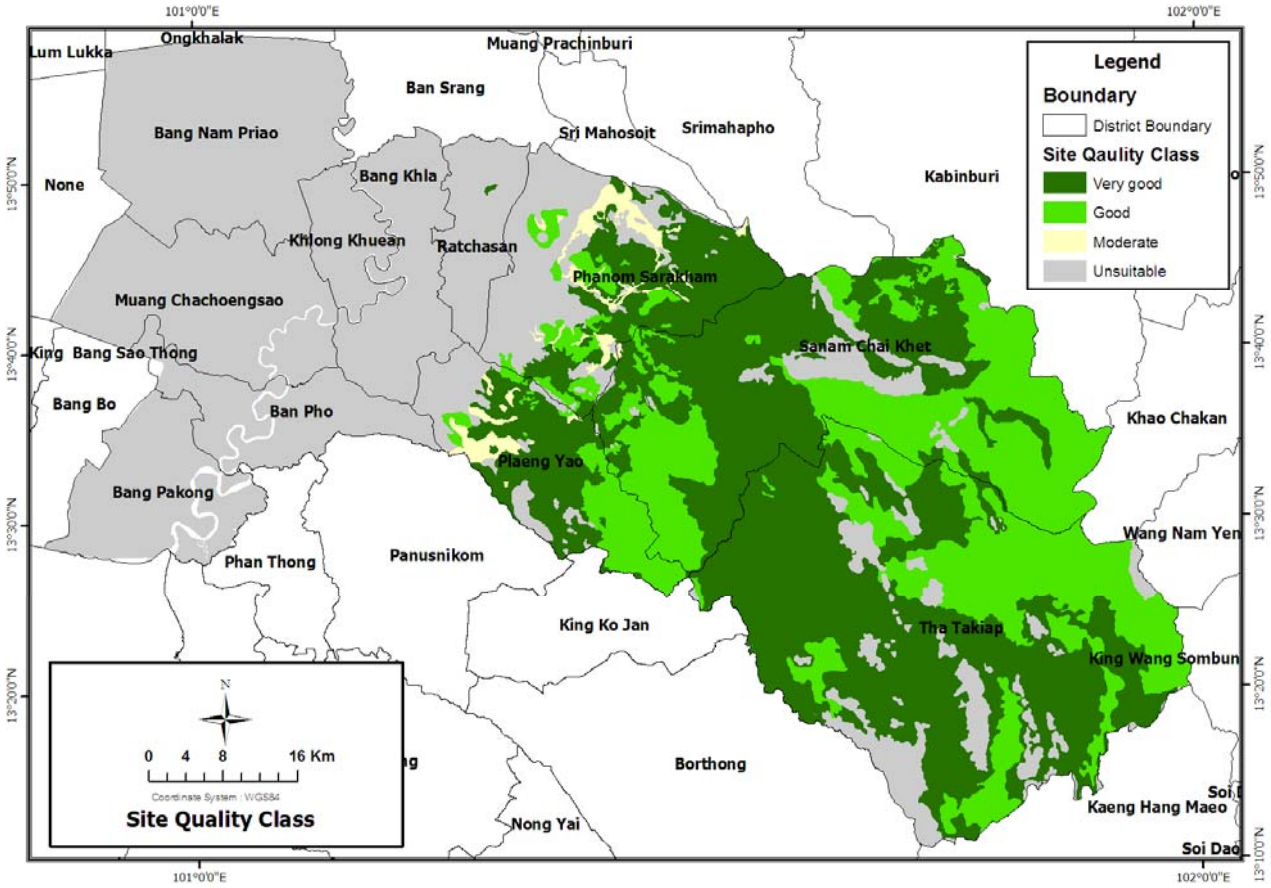


Figure 8 Classification of site suitability for eucalypt planting in Chachoengsao province based on an anamorphosis method on the 3-year basis.

Table 23 Summary area of each site suitability class for eucalypt planting in Chachoengsao province based on an anamorphosis method on the 3-years basis presented in Figure 6

Site suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
Very good		**177,451.48**	**1,109,071.75**	**34.61**
	Alluvial terrace and fan complex			
	Alluvial soils, poorly drained complex (AC-pd)	2,113.45	13,209.09	0.41
	Bang Khla series (Bka)	27,536.72	172,104.48	5.37
	Bang Khla, brown variant (Bka-br)	348.88	2,180.48	0.07
	Ko Khanun series (Kkn)	25,233.75	157,710.97	4.92
	Nong Khok series (Nkk)	4,434.23	27,713.92	0.86
	Pang Rai series (Pg)	18,193.14	113,707.14	3.55
	Pang Rai and Satuk, moderate (Pg&Suk-md)	11,156.83	69,730.20	2.18
	Satuk series (Suk)	9,303.77	58,148.55	1.81
	Satuk and Warin soils (Suk&Wn)	8,146.71	50,916.94	1.59
	Satuk, coarse loamy variant (Suk-col)	3,072.56	19,203.48	0.60
	Satuk, moderately deep variant (Suk-md)	8,056.61	50,353.84	1.57
	Warin series (Wn)	5,427.28	33,920.49	1.06

Table 23 (Continued)

Site suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Erosion surface and local wash			
	Ban Bung series (Bbg)	6,835.80	42,723.74	1.33
	Hup Kapong series (Hg)	1,408.63	8,803.93	0.27
	Hup Kapong and Sattahip soil (Hg&Sh)	491.61	3,072.58	0.10
	Lat Ya/Tha Yang association (Ly/Ty)	29,615.66	185,097.87	5.78
	Map Bon series (Mb)	2,083.58	13,022.39	0.41
	Map Bon, clayey variant (Mb-c)	484.95	3,030.94	0.09
	Sattahip series (Sh)	9,346.82	58,417.62	1.82
	Sattahip, gravelly variant (Sh-gr)	1,114.23	6,963.94	0.22
	Satuk, granite derived variant (Suk-gra)	3,046.27	19,039.17	0.59
Good		**107,481.16**	**671,757.24**	**20.96**
	Alluvial terrace and fan complex			
	Alluvial soils well drained complex (AC-wd)	2,622.47	16,390.45	0.51
	Bang Khla and Bang Khla, brown soils (Bka&Bka-br)	28,624.36	178,902.24	5.58
	Don Rai series (Dr)	5,182.94	32,393.38	1.01

Table 23 (Continued)

Site suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Don Rai and Korat soils (Dr&Kt)	1,483.41	9,271.30	0.29
	Hin Kong series (Hk)	2,641.25	16,507.83	0.52
	Hin Kong/Ko Khanun association (Hk/Kkn)	1,486.19	9,288.67	0.29
	Korat series (Kt)	685.95	4,287.18	0.13
	Phen series (Pn)	792.08	4,950.48	0.15
	Sakon series (Sk)	5,170.26	32,314.10	1.01
	Sakon and Bang Khla and Phon Phisai soils (Sk&Bka&Pp)	10,399.94	64,999.63	2.03
	Erosion surface and local wash			
	Kabin Buri series (Kb)	22,379.18	139,869.89	4.36
	Kabin Buri, brown variant (Kb-br)	3.49	21.82	0.00
	Kabinburi and kabinburi, brown soils (Kb&Kb-br)	14,571.51	91,071.91	2.84
	Kabinburi and kabinburi, brown soils (Kb&Kb-br&Kb-l)	11,158.80	69,742.50	2.18
	Tha Yang (Ty)	279.34	1,745.85	0.05

Table 23 (Continued)

Site suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
Moderate		**6,804.03**	**42,525.19**	**1.33**
	Alluvial terrace and fan complex			
	Chon Buri series (Cb)	6,804.03	42,525.19	1.33
Unsuitable		**221,029.29**	**1,381,433.07**	**43.11**
	Tidal flat			
	Bang pakong series (Bpg)	1,854.35	11,589.67	0.36
	Tha-chin and Bang Pakong series (Tc&Bpg)	2,930.86	18,317.85	0.57
	Former tidal flat			
	Bang nam Priew series (Bp)	11,613.45	72,584.04	2.26
	Bangkok series (Bk)	37,732.30	235,826.87	7.36
	Cha-am series (Ca)	3,534.65	22,091.54	0.69
	ChaChoengsao series (Cc)	65,875.92	411,724.50	12.85
	Don Muang series (Dm)	7,472.60	46,703.77	1.46
	Mahapho series (Ma)	19,368.57	121,053.56	3.78
	Ongkharak series (Ok)	2,756.88	17,230.49	0.54

Table 23 (Continued)

Site suitability class	Soil series	Area (ha)	Area (rai)	Coverage percentage
	Phan Thong series (Ptg)	842.45	5,265.29	0.16
	Rangsit series (Rs)	17,768.18	111,051.12	3.47
	Rangsit, very, acid phase (Rs-a)	2,899.86	18,124.15	0.57
	Samut prakan series (Sm)	5,527.11	34,544.41	1.08
	Undifferentiated ridged acid soils (NBC)	10,547.92	65,924.49	2.06
	Alluvial terrace and fan complex			
	Klaeng series (Kl)	8,058.65	50,366.57	1.57
	Klaeng, overwash phase (Kl-ow)	992.88	6,205.52	0.19
	Slope complex			
	Slope Complex (Sc)	20,722.25	129,514.09	4.04
	Other land uses			
	Other land uses (River, Canal, Lake or Pond) (W, Fsh)	530.43	3,315.16	0.10
Total		**512,765.96**	**3,204,787.25**	**100.00**

Relationship between eucalypt growth and soil properties

The relationship between soil properties and yield (stem biomass) of the 3-year-old eucalypt plantation in each soil series was determined. The multiple regressions between dependent variable of aboveground biomass and the independent variables of soil properties (0-50 cm depth) were analyzed by the backward multiple regression. The following dependent and independent variables are listed below and the data of each soil series available for analysis are given in Table 24.

Dependent variable:

W_s - Aboveground biomass of 3-year-old eucalypt, t ha^{-1}

Independent variables:

Sand - Sand, %

Silt - Silt, %

Clay - Clay, %

pH - Soil reactions

P - Concentration of available phosphorus, mg/kg

C - Concentration of total soil carbon, %

Base - Base saturation, %

Determination of the degree of dependence of the above multiple regressions is summarized below and summary of the backward multiple regression analysis is given in Tables 25 and 26.

$W_s = 82.027 - 1.440\text{Clay} - 0.526\text{P} - 0.249\text{Base}$

$R^2 = 0.934$

$P = 0.001$

Table 24 Aboveground biomass of the 3-year-old eucalypt plantation and soil properties for the multiple regression analysis of the relationship between eucalypt production and soil properties in Chachoengsao province

Site suitability	Soil	Biomass (t ha^{-1})	Sand (%)	Silt (%)	Clay (%)	pH	Phosphorus (mg kg^{-1})	Carbon (%)	Base saturation (%)
Very good	Sh	55.51	81.25	15.50	3.25	5.20	3.25	0.25	83.50
	Suk	44.43	71.95	25.55	2.50	4.70	18.10	0.19	91.00
	Bbg	43.09	82.25	14.50	3.25	5.60	21.15	0.36	100.00
	Wn	41.29	54.00	24.73	21.27	4.43	5.80	0.41	24.67
	Pn	41.50	39.50	36.85	23.65	4.60	2.50	0.73	22.50
Good	Hk	40.44	6.70	72.47	20.83	4.63	3.13	0.47	40.33
	Dr	41.16	61.47	25.43	13.10	5.80	3.27	0.64	80.00
	Ty	40.93	38.43	39.53	22.03	4.95	2.05	0.91	37.00
	Sk	36.27	42.25	42.00	15.75	5.20	3.25	0.25	83.50

Table 25 A summary of the multiple regression analysis of the relationship between independent variable of aboveground biomass of the 3-year-old eucalypts and independent variables of clay, available phosphorus and base saturation

Source	Sum of squares	df	Mean square	F	*P* values
Regression	213.401	3	71.134	38.600	0.001
Residual	9.214	5	1.843		
Total	222.615	8			

Table 26 Coefficients of the multiple regression analysis of the relationship between independent variable of aboveground biomass of the 3-year-old eucalypts and independent variables of clay, available phosphorus and base saturation

Dependent variable	Coefficients	Std. error	t	*P*-value
Constant	82.027	4.277	19.181	<0.001
Clay	-1.440	0.140	-10.263	<0.001
P	-0.526	0.093	-5.681	0.002
Base	-0.249	0.036	-6.977	0.001

It can be concluded from the regression equation that yield of eucalypt plantations increases with a decrease in clay, available P and base saturation, respectively. Overall, the high productivity occurs when eucalypts grow on the site with decreasing clay particle, probably leading to better soil drainage. Generally, factors influencing soil drainage include topography, ground water level, and soil physical properties (texture, porosity). Suitable soils for eucalypt planting in the current study can be generally observed on upland soils, moderately well to well drained. Adverse effects of poorly drained soils on growth and performance of eucalypt clones planted in Ratchaburi province have been recently reported (Busaba, 2004).

Not only clay particle but also available P and base saturation adversely affect eucalypt growth and yield regardless of remarkably low available P and high base saturation in most soil series analyzed in the present study (Table 24). Both positive and negative effects of available P on eucalypt yield were reported depending soil depth (Insuan, 2005).

Generally, eucalypts can grow well under a wide range of soil conditions ranging from humid to arid areas, low to high fertility and saline to acid soil (Homchan *et al*., 1989). Some particular soil properties also play an important role in growth performance of eucalypts including soil nutrients, texture, structure, reactions, and organic matters. Correlation of eucalypt growth/yield and soil properties has widely been published. Thaiutsa *et al*. (2004) found that the relationship between eucalypt yields observed in northeastern part of Thailand varied considerably with soil depth. The eucalypt yield depended largely on particle/bulk density, soil reactions, and porosity observed for surface soils, while importance of soil nutrients and organic matters became more pronounced in deeper soils.

The relationship between eucalypt production and some soil properties derived from LDD was analyzed based on a small number of soil series available in the present study (Table 24), leading to insufficient information for site management recommendation. In each sampling plot, if the determination of soil properties was undertaken in relation to growth data, the relationship between yield of eucalypt plantations and soil properties could have provided conclusive information for recommendation on site management in the DSS for the eucalypt plantation investment. Recommendation on site management in the DSS is, however, given based on general characteristics of each soil series.

Financial analysis

Cost benefit analysis in terms of B/C ratio and NPV was carried out to recommend users whether the investment of eucalypt plantation is economically worthwhile. These involved estimating the aggregate benefits and costs in monetary

terms for the whole rotation as summarized in Table 27. The typical eucalypt plantations were generally profitable on rotations of 3-5 years, and the economic productivity varied with site qualities, ranging from average stem fresh weights of 19.20-31.84, 16.26-26.96 and 13.33-22.10 t rai^{-1} for very good, good and moderate sites respectively (Table 28). The average price of stem fresh weight was taken to be 1,250 baht t^{-1} (US$ 1= about 33 baht), based on the timber price in 2008 given by the targeted entrepreneurs in the study area. The price is understood to be for timber larger than 2.5 inches in diameter, including bark, sold at the spot market. Costs for harvesting and transportation were, therefore, necessary to be included to the total cost.

Table 27 List of benefits and costs of eucalypt plantation investment in Chachoengsao province, based on 400 trees per rai and up to 5-year rotation

Items	Price	Unit	Benefits or costs				
			1st year	2nd year	3rd year	4th year	5th year
Benefits	1,250	baht/ton	✖	✖	✓	✓	✓
Costs							
Land rent	400	baht/rai	✓	✓	✓	✓	✓
Establishment							
Site preparation	350	baht/rai	✓	✖	✖	✖	✖
Seedlings	1,200	baht/rai	✓	✖	✖	✖	✖
Planting	170	baht/rai	✓	✖	✖	✖	✖
Fertilizer application	300	baht/rai	✓	✖	✖	✖	✖
Tending							
Fertilizer application	250	baht/rai	✖	✓	✓	✖	✖
Weeding							
- weeds	300	baht/rai	✓	✖	✖	✖	✖
- climbers	20	baht/rai	✖	✓	✓	✓	✖
Ploughing	120	baht/rai	✓	✓	✓	✓	✖
Insecticide application	140	baht/rai	✖	✓	✓	✓	✖
Firebreak construction	20	baht/rai	✓	✓	✓	✓	✓
Harvesting	130	baht/ton	✖	✖	✓	✓	✓
Transportation	170	baht/ton	✖	✖	✓	✓	✓

Remarks The prices given by the targeted entrepreneurs in the study area in 2008

As presented in Table 27, investment cost included all costs of eucalypt planting occurring practically for the whole rotation, from site preparation through transportation to a spot market, based on 400 trees rai^{-1} and up to 5-year rotation. The costs were mainly establishment costs of 2,020 baht rai^{-1}, while transportation and harvesting costs accounted for 13.6 and 10.4% of timber price, respectively.

The financial analysis revealed that the profits from eucalypt planatations varied remarkably with site qualities and rotations. For all site qualities, the B/C ratios were greater than 1 and the NPV values were also positive after 3 years as shown in Table 28. Higher B/C ratios and NPV values were also observed in longer rotations. The finding suggested that the investments of eucalypt plantation were economically profitable after 3 years for all site qualities and even more worthwhile for longer rotations as the tending costs decreased after a few years of establishment. In Southern China, Xu (2003) set up cost scenarios for eucalypt plantation on different establishment and management regimes to compare economic returns of the first and second rotations. The result suggested that the investment tended to gain more profits after the first rotation despite of lower productivity of the second one. This was mainly because, in the second rotation, establishment costs were deduced and tending costs were minimal. Reduced productivity of eucalypt plantations in the second rotation of coppice stand was often found as previously reported (Xu *et al*., 2000; Jiang *et al*. 2002; Watchrinrat, 2003).

In addition, another means to increase economical benefits is to increase productivity by establishing eucalypt plantations on better site qualities. In the current study, the markedly higher B/C ratios and NPV values were observed for very good site quality, compared to those for good and moderate site qualities, respectively. The finding clearly indicates greater profits for plantations established on better site qualities with higher productivity (Table 28). Overall, site selection and plantation establishment and management are key factors affecting the economic benefit from commercial eucalypt plantation investment.

Table 28 Cost-benefit analysis of eucalypt plantation investment on different site suitability classes in Chachoengsao province

Site suitability class	Rotation (years)	Yield (t rai^{-1})	Benefit (baht)	Cost (baht)	B/C ratio	NPV (baht)
Very good	3	19.20	23,998.14	10,519.55	2.11	8,994.77
	4	23.79	29,733.81	12,596.11	2.11	9,929.28
	5	31.84	39,798.77	15,431.70	2.24	12,492.72
Good	3	16.26	20,323.13	9,637.55	1.94	7,006.76
	4	20.14	25,180.46	11,503.31	1.93	7,730.04
	5	26.96	33,704.11	13,968.99	2.07	9,864.43
Moderate	3	13.33	16,658.65	8,758.07	1.74	5,024.45
	4	16.51	20,640.15	10,413.64	1.73	5,537.10
	5	22.10	27,626.91	12,510.46	1.86	7,243.67

Remarks Financial analysis based on 7% of loan interest rate and 12% of deflation rate.

DSS procedure

According to the conceptual framework as shown in Figure 2, the DSS for eucalypt plantation investment in Chachoengsao province can be separated into 4 main parts, namely input data, system database, data analysis, and system output. In order to clarify the choice situation of the user-defined location, however, decision hierarchy was constructed as depicted in Figure 9. The top of the hierarchy involves input data of a land location, which is defined by users. The system specifies whether the user-defined location is in the Chachoengsao boundary. Subsequently, the location falling within water boundaries or protected areas is basically excluded from the DSS procedure as not within possible areas for commercial plantations. On the other hand, the location, which does not meet such criteria, is then categorized into the following four classes of site suitability for eucalypt planting (Figure 8 and Table 23):

- Site suitability class 0: unsuitable site;
- Site suitability class 1: moderate site quality;
- Site suitability class 2: good site quality; and
- Site suitability class 3: very good site quality

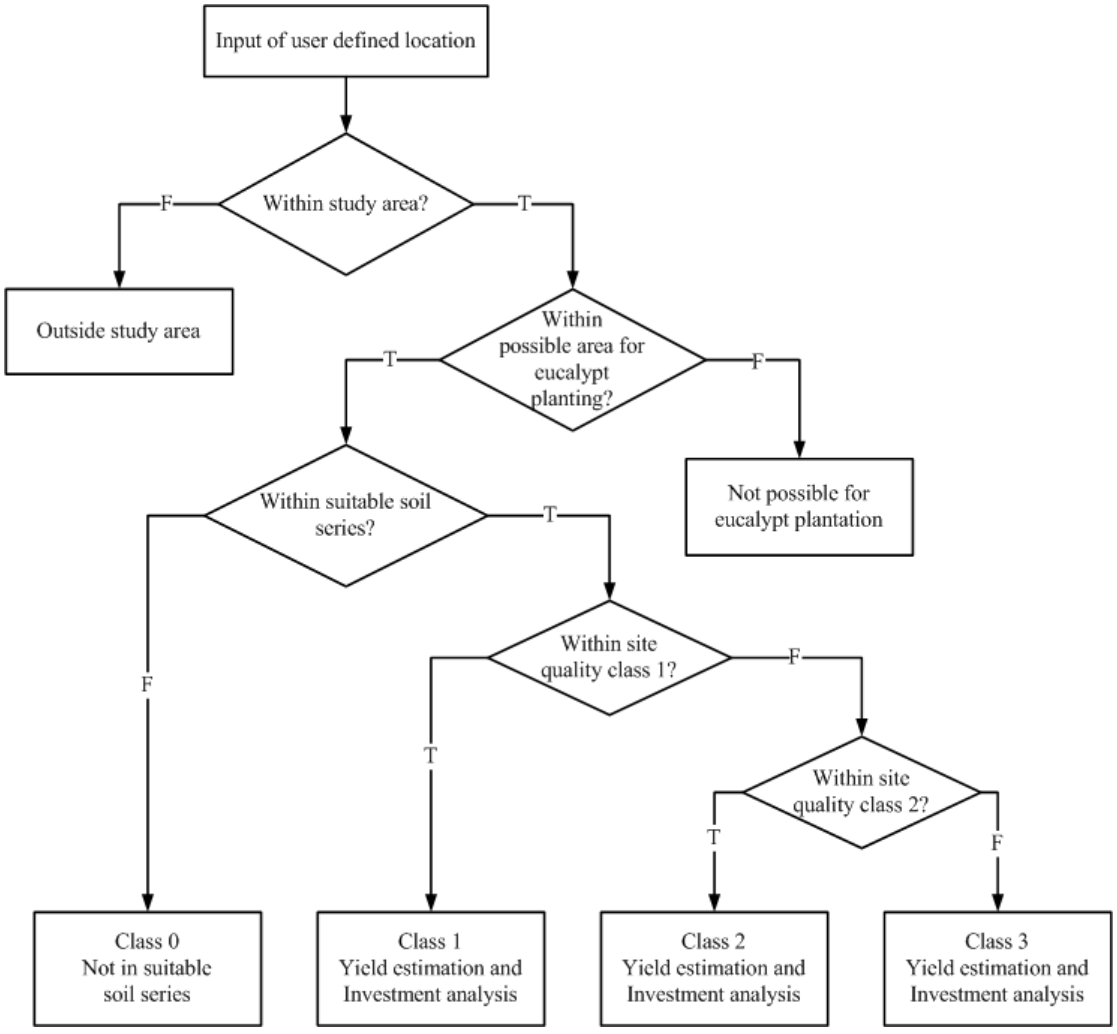


Figure 9 Decision hierarchies of the DSS for eucalypt plantation investment in Chachoengsao province.

The system proceeds further where the user-defined location is categorized into classes 1-3. Yield estimation and financial analysis of the suitable soil series for eucalypt planting based on a site quality are then determined. The financial analysis reports and recommendation for management program of eucalypt planting with cost estimation are also provided accordlingly.

A hierarchical approach to DSS is very conceptually appealing and has been widely used for forest planning, for example, forest planning for forest ecosystem management (Church *et al*., 2000) and landscape ecological forest planning (Kangas *et al*., 2000). Commonly, the scaling principles were applied so that the importance or priorities of forest plans with respect to the objective measures summed to one. In this study, the decision hierarchy was simplified to clarify choice situation in the form of true (T) or False (F) and detailed information was provided accordingly as depicted in Figure 9.

DSS user interface design

The management system of user interface was designed according to the user-friendly interactive concept for simplicity and high information content. Due to such a concept, the Thai system language was applied to simply communicate with Thai entrepreneurs/farmers. The user interface design, which is used to communicate with users step by step, includes welcome homepage, input data pages, interactive pages and output pages, as shown in Figures 10-22.

The welcome homepage provides general information on the DSS, e.g. introduction, instruction as presented in Figure 10. After entering the system from the welcome homepage, the DSS requires a user to define location of the land on the input data page by entering the land coordinate or choosing from the map (Figure 11). The coordinate converter interactive page is also alternatively provided as preferred (Figure 12). Once the user-defined location has been entered, decision hierarchy is proceeded to clarify whether the location meets criteria of possibility for eucalypt planting. Interactive pages or notifications to users step by step is made by dialogue

boxes (Figure 13). If the user-defined location is within possible areas for eucalypt planting, classification of soil series, soil description, climatic data and classification of site suitability for eucalypt planting are provided as presented in Figure 14 (unsuitable site) and Figure 15 (suitable site). Users could also obtain detailed information on soil characteristics of the defined soil series as preferred (Figure 16). For suitable site, yield estimation and financial analysis are proceeded accordingly. The pre-defined financial data set is provided and allowed to modify by users to suit the current financial situations (Figure 17) and the system requires users to confirm the choice decision (Figure 18). The output pages are displayed to provide information on wood production, benefits, and aggregate costs of plantation investment as well as choices for investment financial analysis (Figure 19). Subsequently, a financial analysis in particular year of investment, 3-5 years, is given with detailed information on financial parameters (Figure 20). Summary report output page is also displayed to compare the financial analysis results in each choice rotation as presented in Figure 21. Furthermore, the user interface design allows users to print out all reports as required (Figure 22).

However, limitations of the DSS in the present study occur where the defined land falling into the following categories: (1) outside the Chachoengsao province boundary; (2) inside the water boundaries; or (3) inside the protected areas. Dialogue boxes appear to keep the users informed case by case where limitation occurs (Figure 13). Based upon the user-friendly interactive concept, the DSS for eucalypt plantation investment in the present study has been developed by interviewing a number of relevant users, e.g. researchers, entrepreneurs.

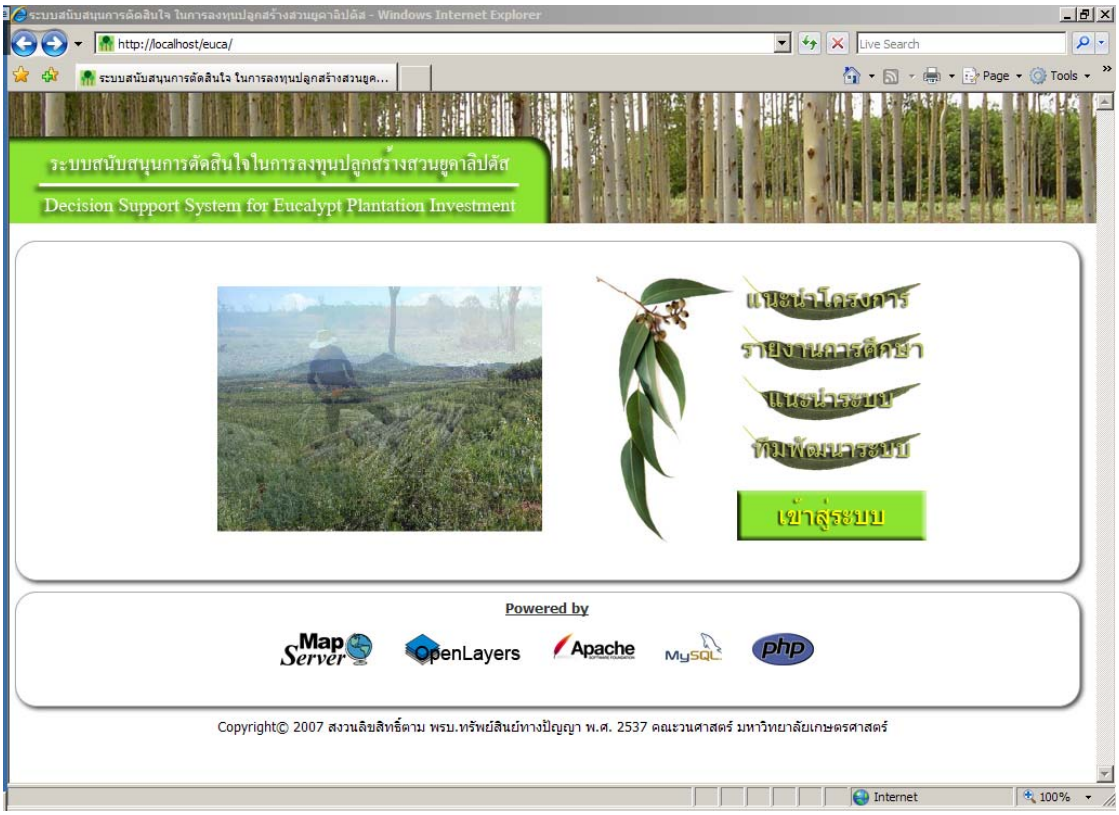


Figure 10 Welcome homepage in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

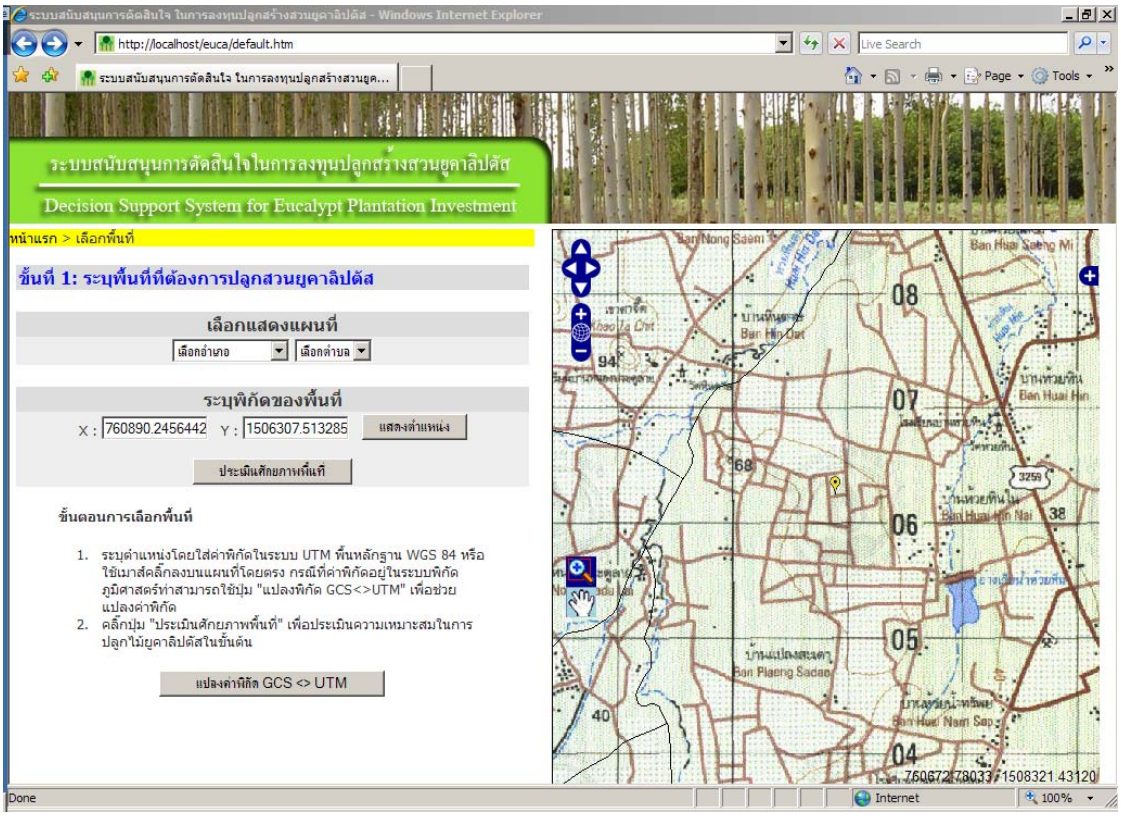


Figure 11 Input data page of user-defined coordinate in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

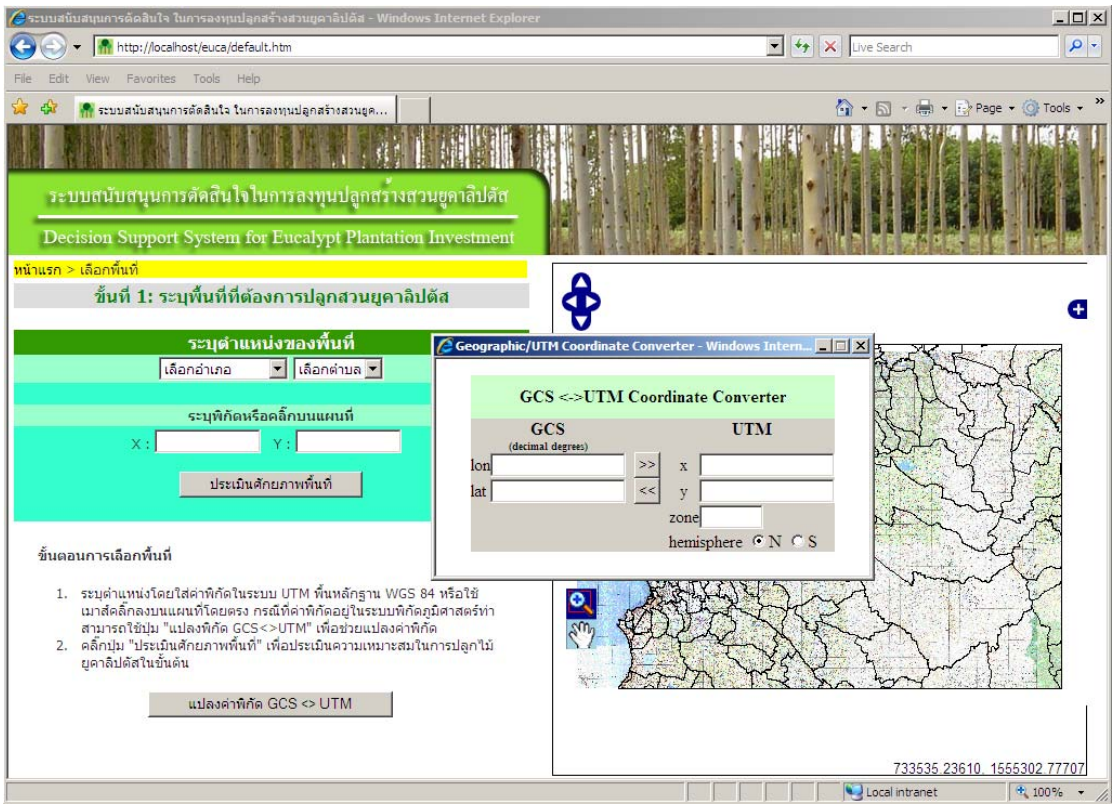
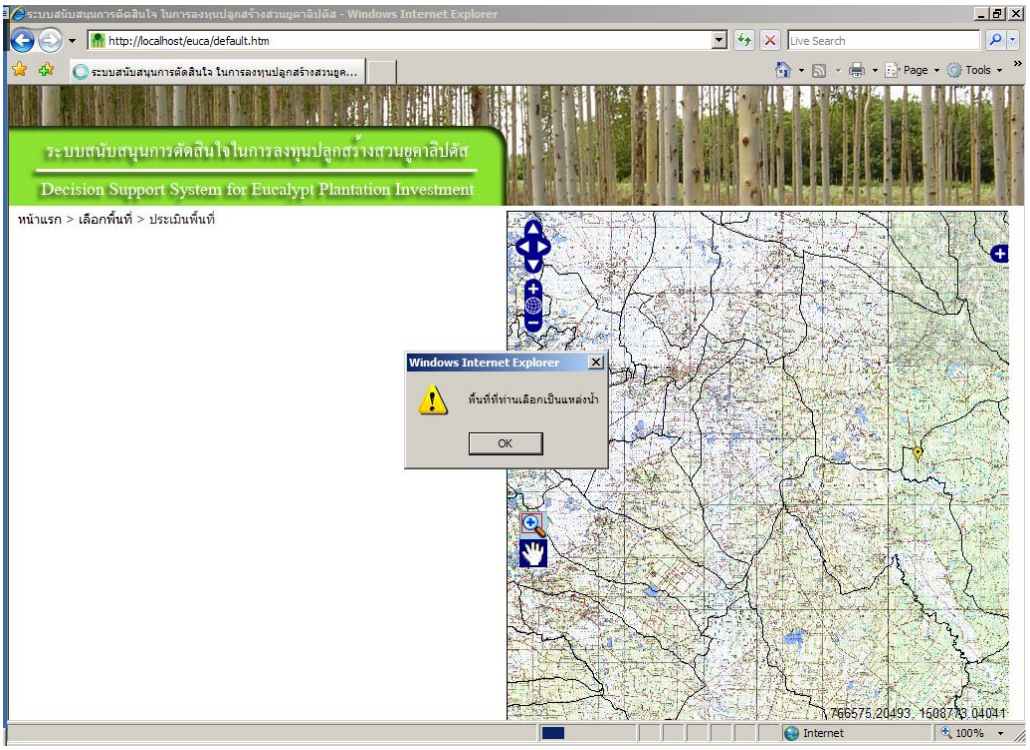


Figure 12 Input data page of coordinate converter in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.



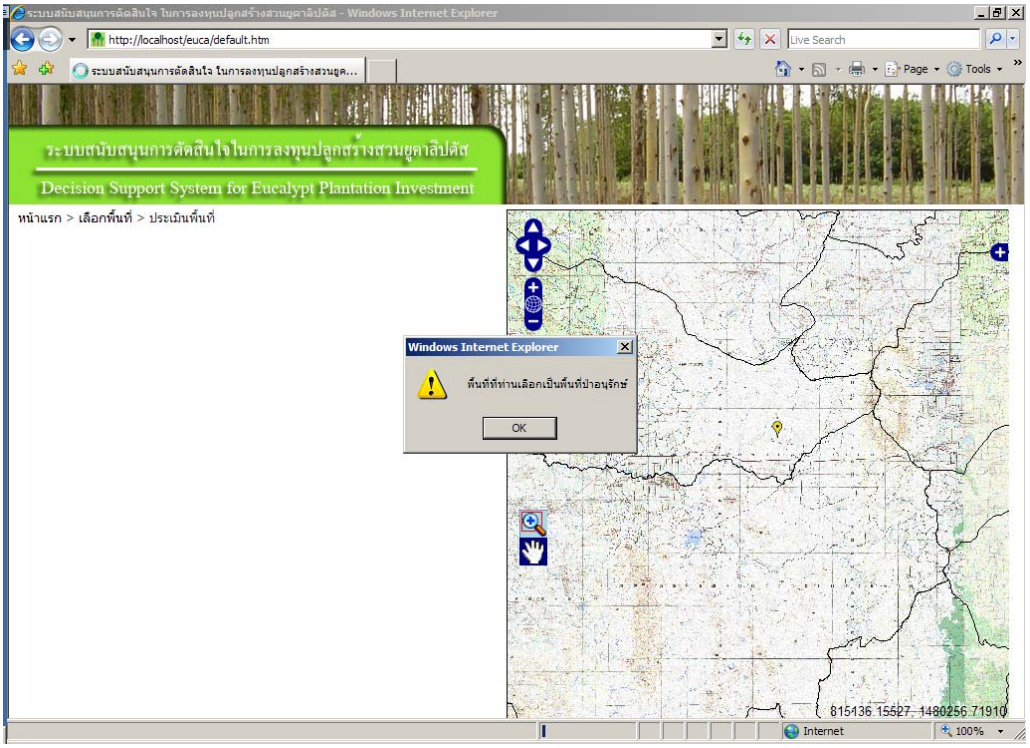


Figure 13 Interactive pages in the DSS user interface design for eucalypt plantation investment in Chachoengsao province

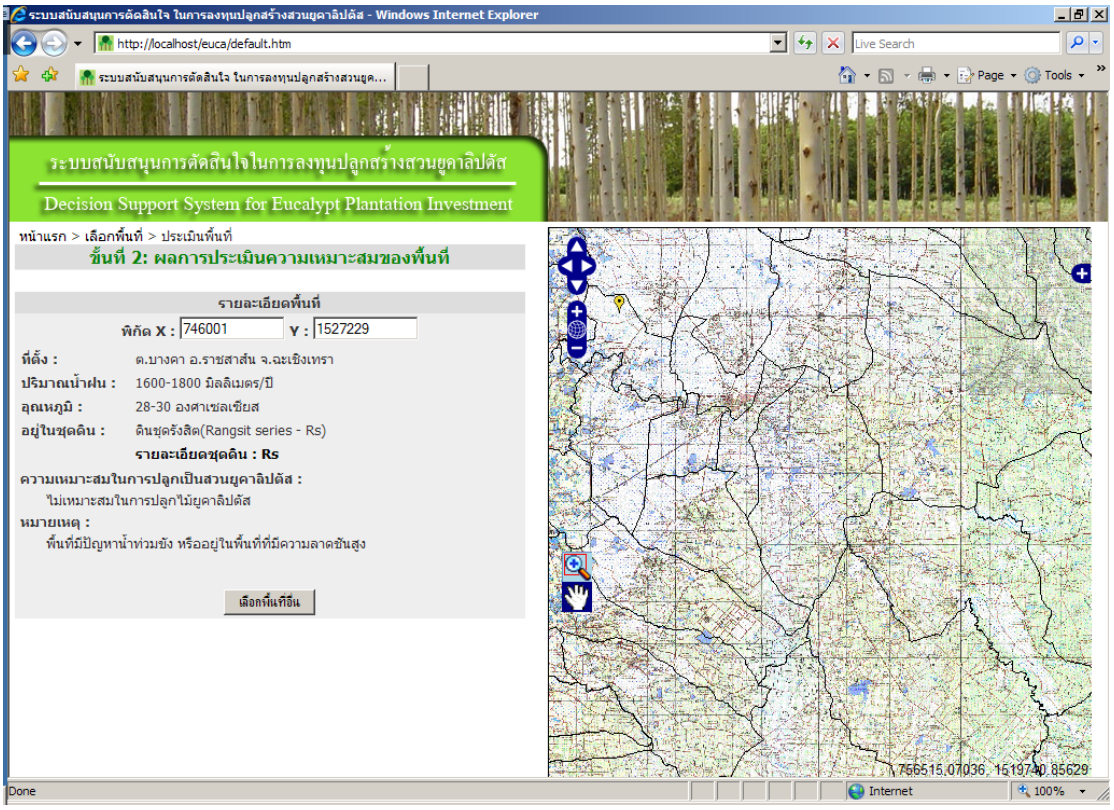


Figure 14 Output page of preliminary site suitability report in a case of unsuitable site in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

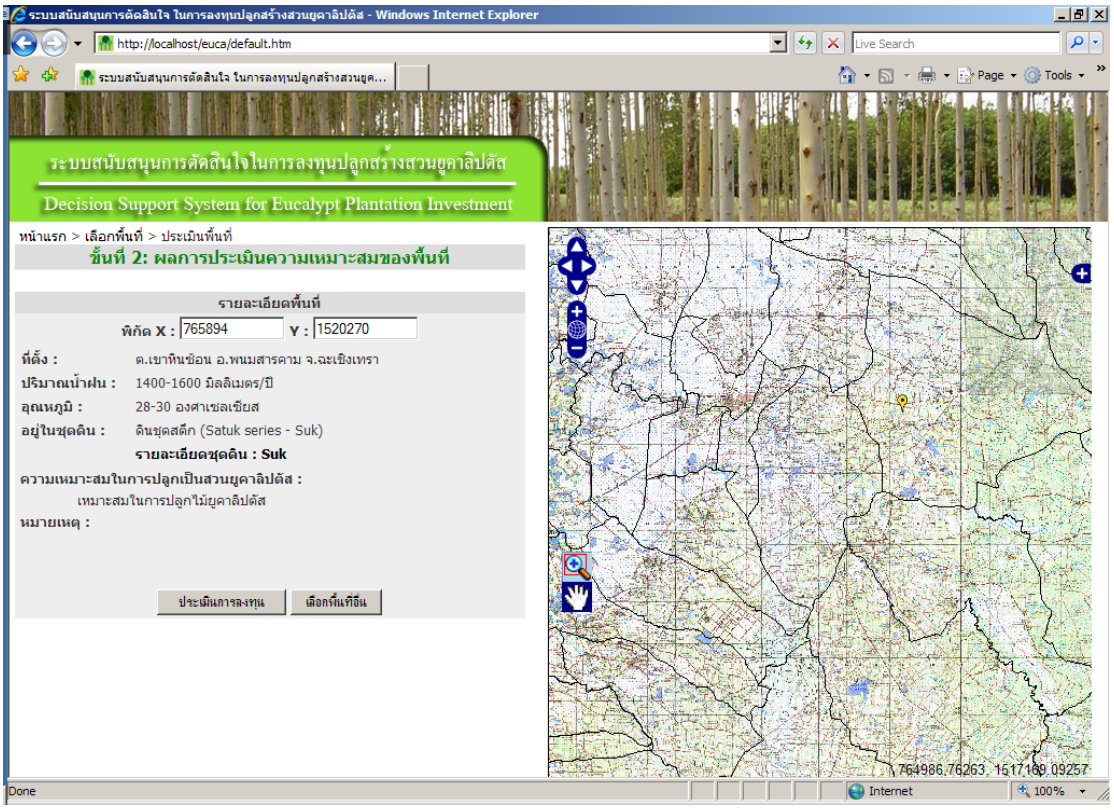


Figure 15 Output page of preliminary site suitability report in a case of suitable site in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

Figure 16 Output page of soil characteristics report in the DSS user interface design for eucalypt plantation investment in Chachoengsao province

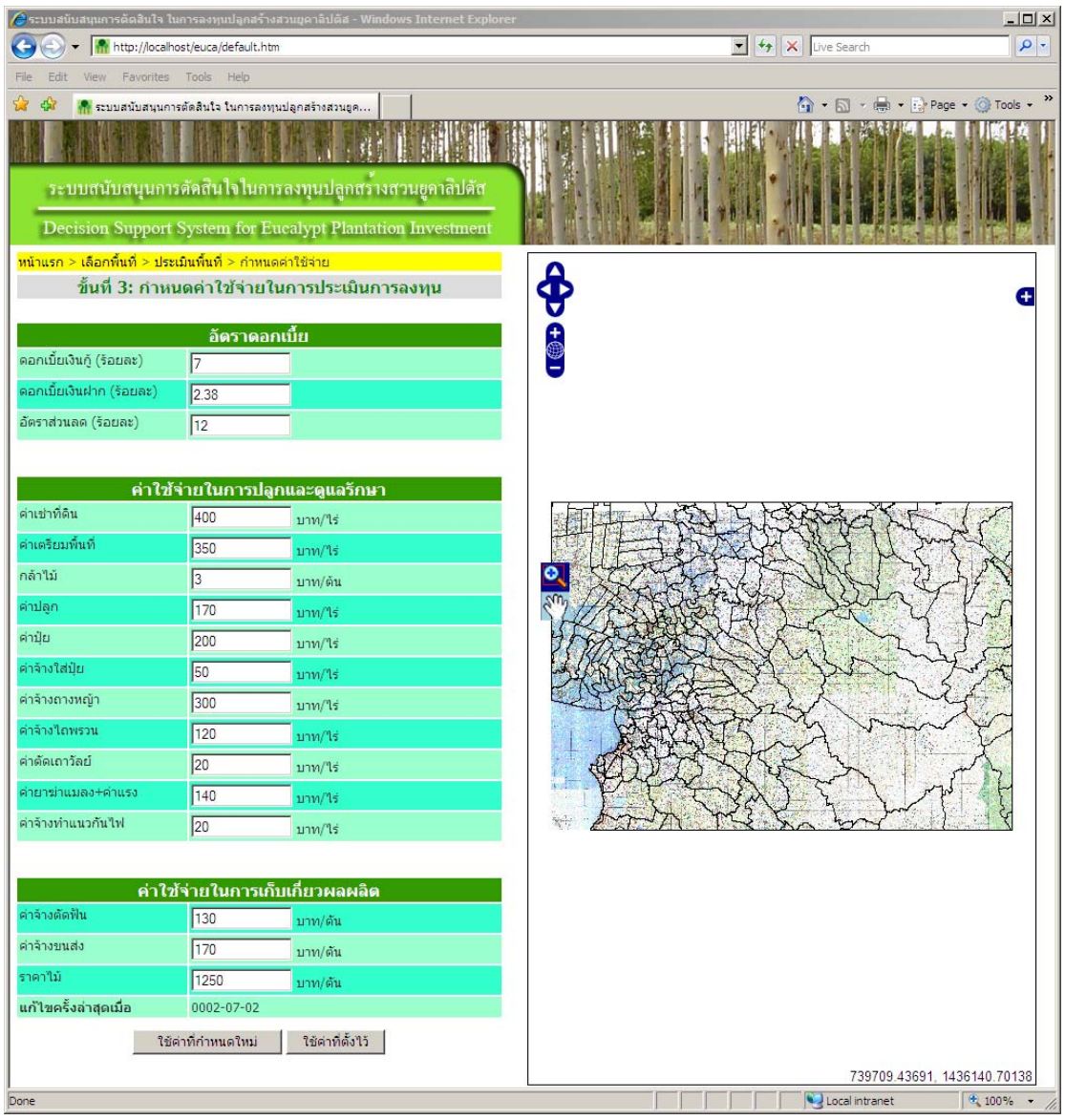


Figure 17 Input data page of financial data set in the DSS user interface design for eucalypt plantation investment in Chachoengsao province

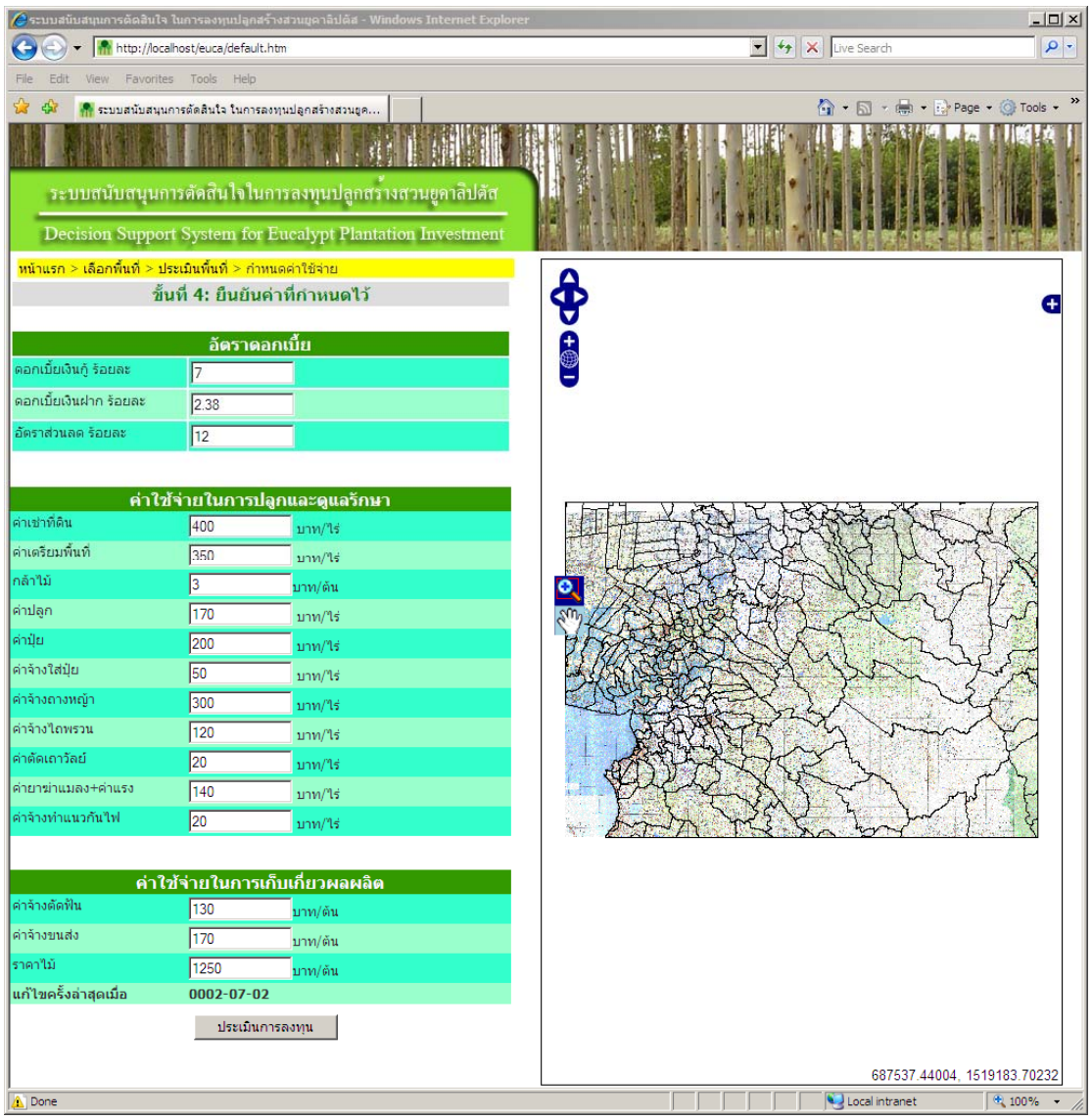


Figure 18 Input page of financial data set confirmation in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

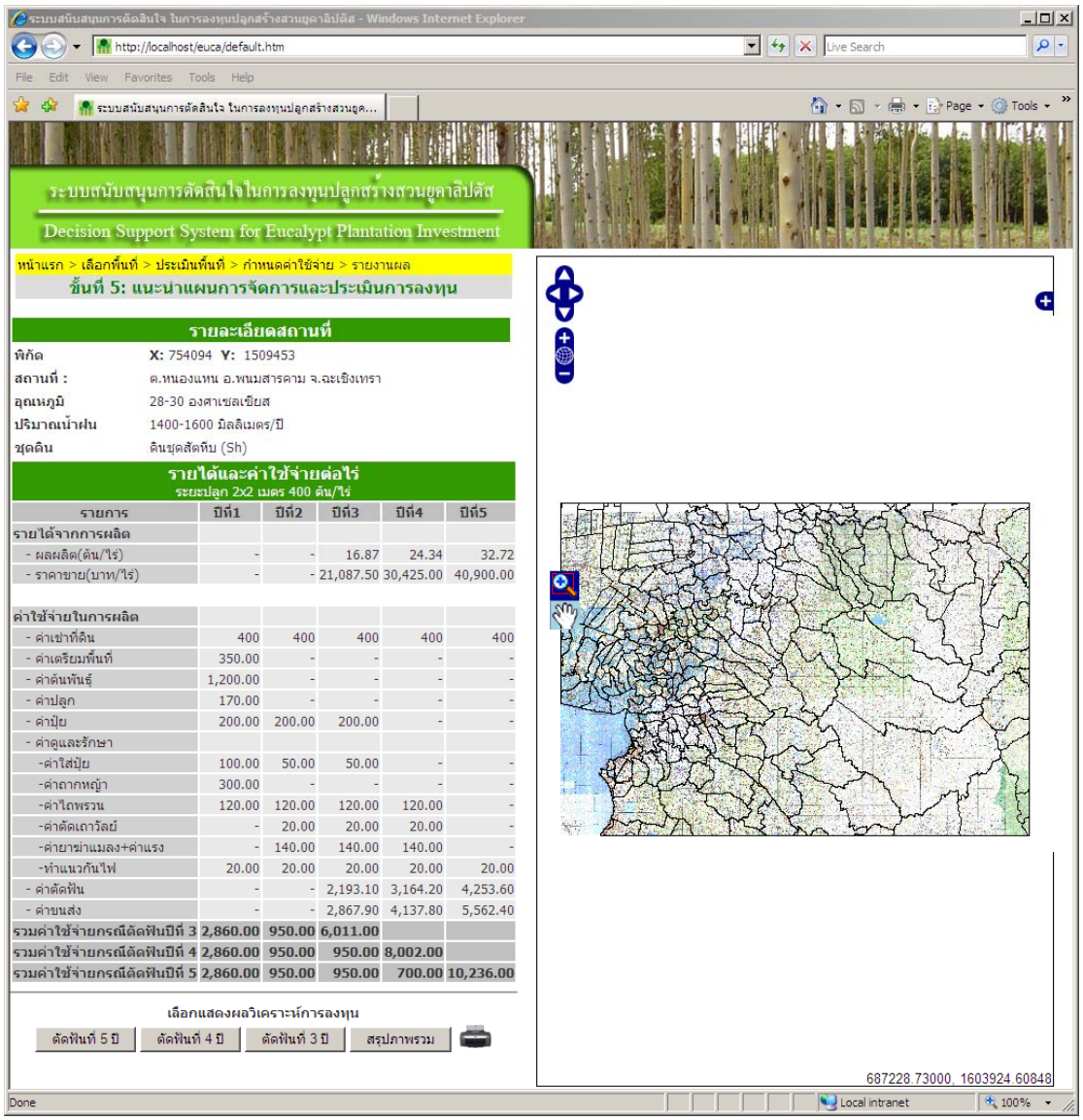


Figure 19 Input data page of financial data set in the DSS user interface design for eucalypt plantation investment in Chachoengsao province

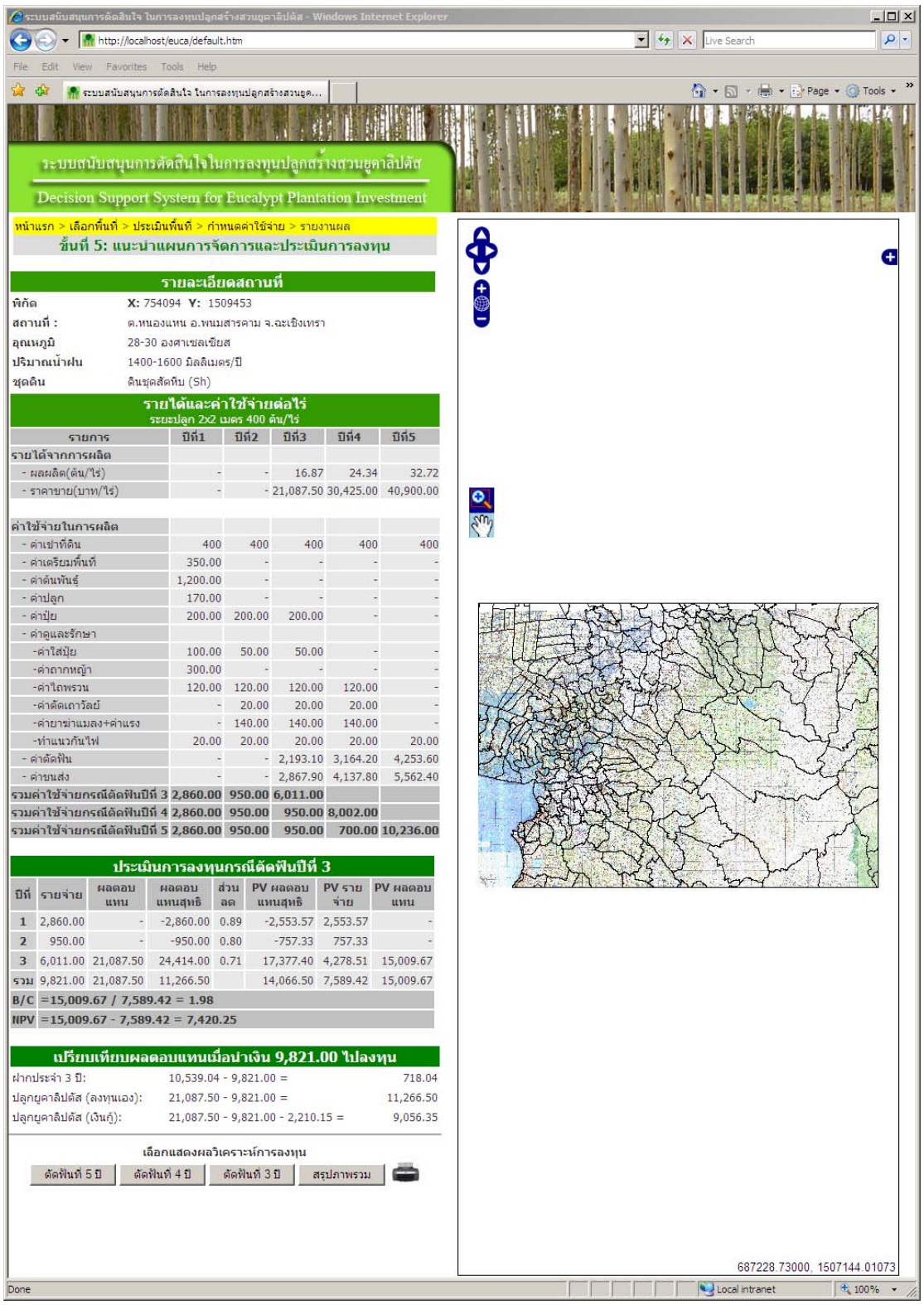


Figure 20 Output page of financial analysis in the DSS user interface design for eucalypt plantation investment in Chachoengsao province

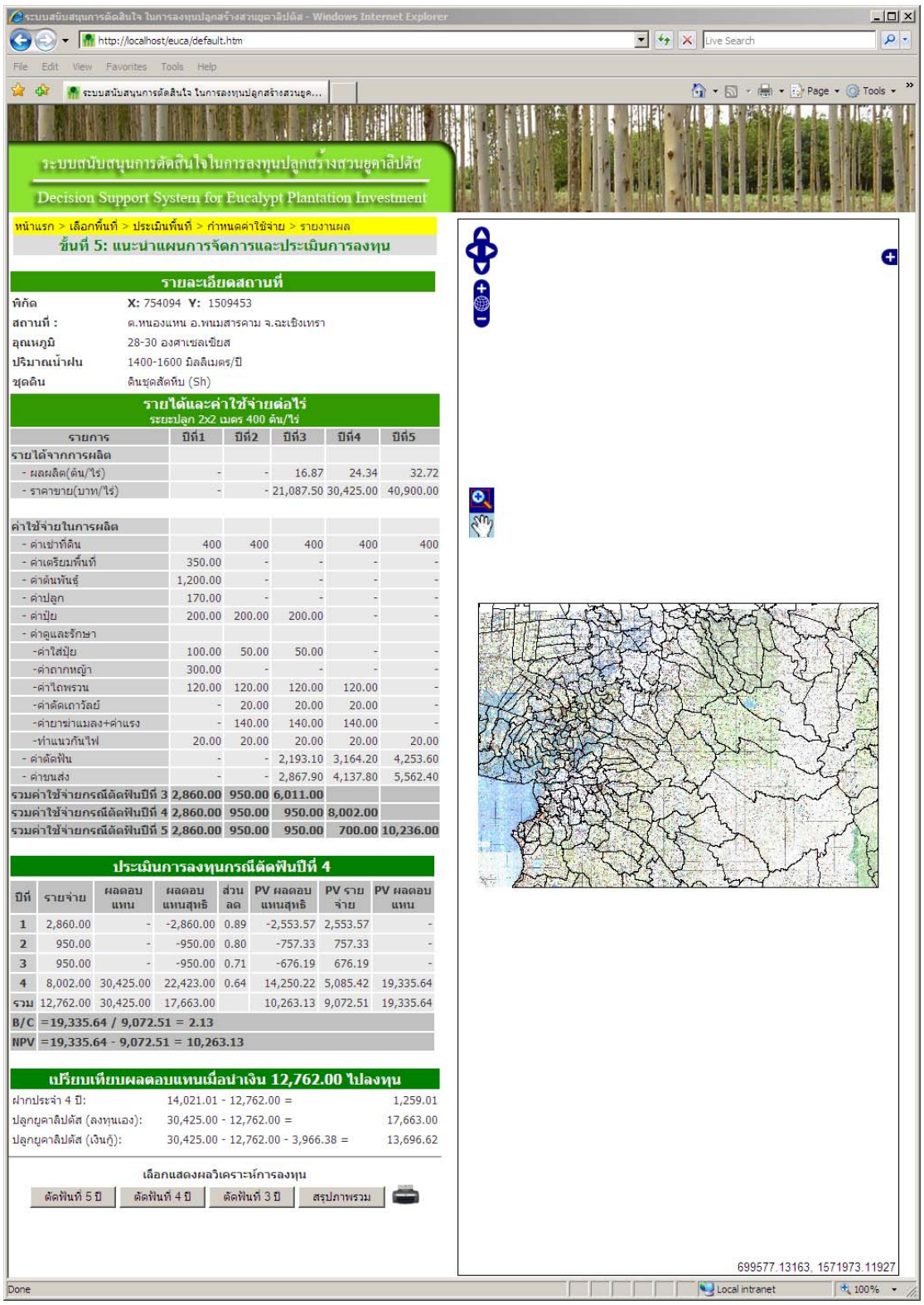


Figure 20 (Continued)

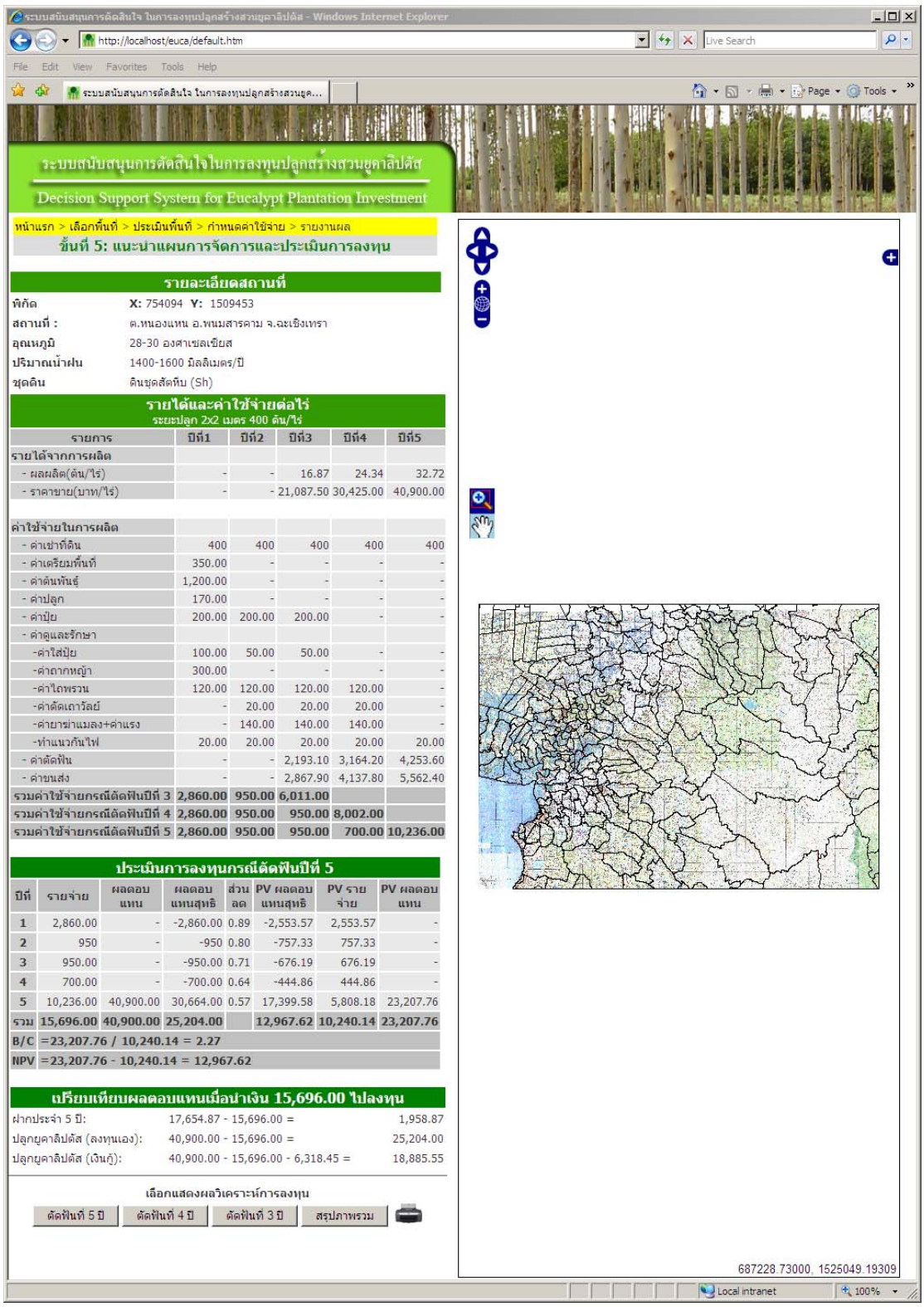


Figure 20 (Continued)

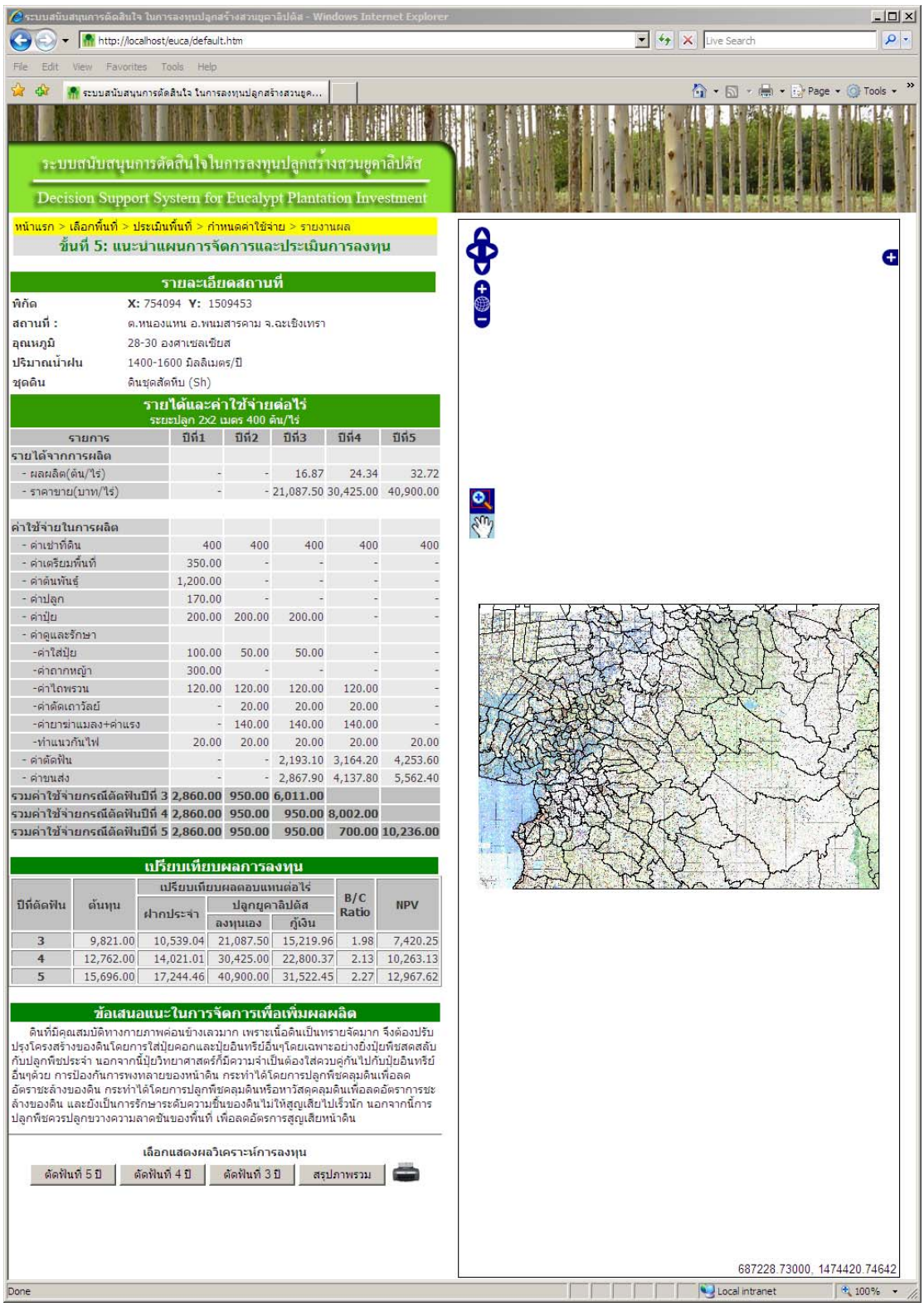


Figure 21 Output page of summary report in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

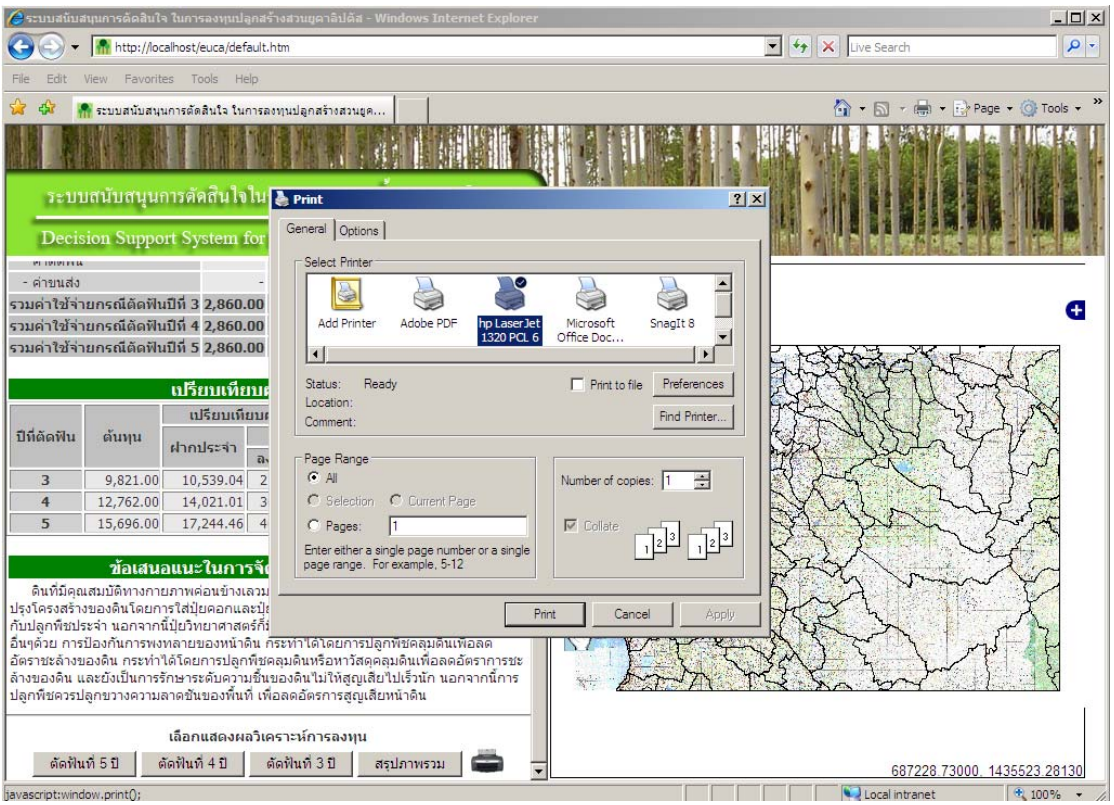


Figure 22 Dialogue box displaying printing report in the DSS user interface design for eucalypt plantation investment in Chachoengsao province.

DSS output

In order to meet all specific objectives of the DSS for eucalypt plantation investment developed in the present study, 3 types of output page was designed, i.e. preliminary report, financial report, and summary report.

Output pages of preliminary report are displayed to provide information on site characteristics, soil series description, and climatic data (temperature and rainfall) as well as classification of site suitability (Figures 14 and 15). Site characteristics are generally displayed in forms of topographic information such as district, sub-district, land-use type etc. Soil description, including general description, physical and chemical properties and recommendation for agricultural crops, is provided based upon the soil series of the location. Generally, there are 53 soil series in Chachoengsao

province (Figure 4, Table 16). The DSS also classifies site suitability for eucalypt planting into four classes, i.e. class 0 unsuitable site, class 1 moderate site quality, class 2 good site quality, and class 3 very good site quality. Based on the result presented in Figure 6 and Table 22, there are 16, 1, 15, and 21 soil series categorized into the four site suitability classes, respectively. In addition to site suitability class, the page also provides general information of the defined area, e.g. coordinate, administrative boundary, temperature data, rainfall data. Detailed information on soil description and characteristics of the soil series of the defined area is given in separate output page as preferred (Figure 16).

Output pages of financial report are given to provide detailed information for benefits from wood production and aggregate costs throughout the 5-year rotation (Figure 19) and the investment analysis (Figure 20). The investment analysis is given in the DSS output to provide financial analysis for decision making in the forms of Benefit/Cost ratio and NPV. Timber production and benefits, and costs occurring throughout the plantation management program are provided. To maximize the economical profits, the financial parameters are compared where the choice of harvesting is undertaken at 3, 4 or 5 years. Additionally, the DSS also demonstrates choices of economic returns depending on sources of investment. Current deposit and loan interest rates are applied in case of users investing their own money or loaning from financial organizations, respectively.

Finally, an output page of summary report is given to briefly provide all information needed for decision making of eucalypt plantation investment as follows:

- General information of the defined area, e.g. coordinate, administrative boundary, temperature data, rainfall data, soil description;
- Wood production and benefits;
- Costs occurring throughout the plantation management program, e.g. land rent, establishment, tending, harvesting, transportation;
- Financial analysis, i.e. B/C ratios, NPV; and

- Recommendation for plantation establishment and management depending on soil characteristics.

Overall, the DSS output designed in the current study provides 4 categories of information accrodingly, i.e. general information, site suitability classification, investment analysis, and recommendation for plantation management to meet all requirements for eucalypt plantation investment.

DSS evaluation

To evaluate the DSS for eucalypt plantation investment in the study area, growth data of other 34 sampling plots, of which growth and yield data were not used for classification of site quality, were undertaken in 7 soil series. The economic yield (stem fresh weight) was then analyzed to compare with that obtained from the DSS in the respective soil series. The results indicated rather large variation in residuals, ranging from -3.33 to +15.30 t rai^{-1} with an average of 2.43 t rai^{-1} or 16.63% of observed values (Table 28). This may probably be due to great variation in the observed yield in each age class and soil series, particularly in older stands. Specificailly, the yield of 5-year-old eucalypt plantation observed in the Bka varied greatly from 17.42-31.88 t rai^{-1} (Table 29). The scatter diagram of the relationship between observed and estimated values in each age class also emphasized that overestimation of the plantation yield obtained from the DSS were more pronounced in older stands compared to the younger ones (Figure 23). At 2-3 years of age, the residual varied from -4.40 to 6.67 t rai^{-1} (-18.64 to 53.27%), while the values increased up to 14.42 t rai^{-1} (82.80%) at 5 years old. The finding suggested that the economical profits predicted by the DSS could be overestimated in longer rotation, especially 4-5 years.

Table 29 Comparison of observed and estimated economic production (stem fresh weight) by DSS for eucalypt plantation investment in Chachoengsao province

Soil series	Age (years)	Economic production (t rai^{-1})		Residual	
		Observed	Estimated	(t rai^{-1})	(% of observed value)
Bka	2	11.82	12.57	0.74	6.29
Bka&Bka-br	2	9.49	10.64	1.15	12.13
Bka&Bka-br	2	9.69	10.64	0.95	9.83
Bka&Bka-br	2	10.25	10.64	0.40	3.88
Hk	2	11.02	10.64	-0.38	-3.41
Kb	2	10.77	10.64	-0.13	-1.19
Sk&Bka&Pp	2	11.22	10.64	-0.57	-5.10
Suk	2	8.89	12.57	3.67	41.32
Wn	2	7.20	10.64	3.45	47.89
Wn	2	8.75	10.64	1.89	21.64
Bka	3	16.34	19.20	2.86	17.50
Bka	3	17.84	19.20	1.36	7.60
Bka	3	18.24	19.20	0.96	5.27
Bka&Bka-br	3	17.09	16.26	-0.83	-4.86
Hk	3	10.78	16.26	5.48	50.87
Ly/Ty	3	21.77	19.20	-2.57	-11.80
Pg	3	12.53	19.20	6.67	53.27
Pg	3	19.52	19.20	-0.32	-1.66
Sh	3	21.61	19.20	-2.41	-11.17
Suk-md	3	23.60	19.20	-4.40	-18.64
Wn	3	14.33	16.26	1.93	13.43
Bka	4	19.15	23.79	4.63	24.20
Bka	4	20.36	23.79	3.42	16.82
Bka&Bka-br	4	14.64	20.14	5.50	37.55
Kkn	4	30.00	23.79	-6.22	-20.72
Pg	4	23.76	23.79	0.02	0.10
Sk&Bka&Pp	4	12.81	20.14	7.34	57.28
Sk&Bka&Pp	4	16.32	20.14	3.82	23.40
Suk	4	15.58	23.79	8.20	52.64
Wn	4	22.23	20.14	-2.08	-9.36
Bka	5	17.42	31.84	14.42	82.80
Bka	5	21.04	31.84	10.80	51.30
Bka	5	23.83	31.84	8.01	33.63
Bka	5	31.88	31.84	-0.04	-0.13
Average				2.29	17.14

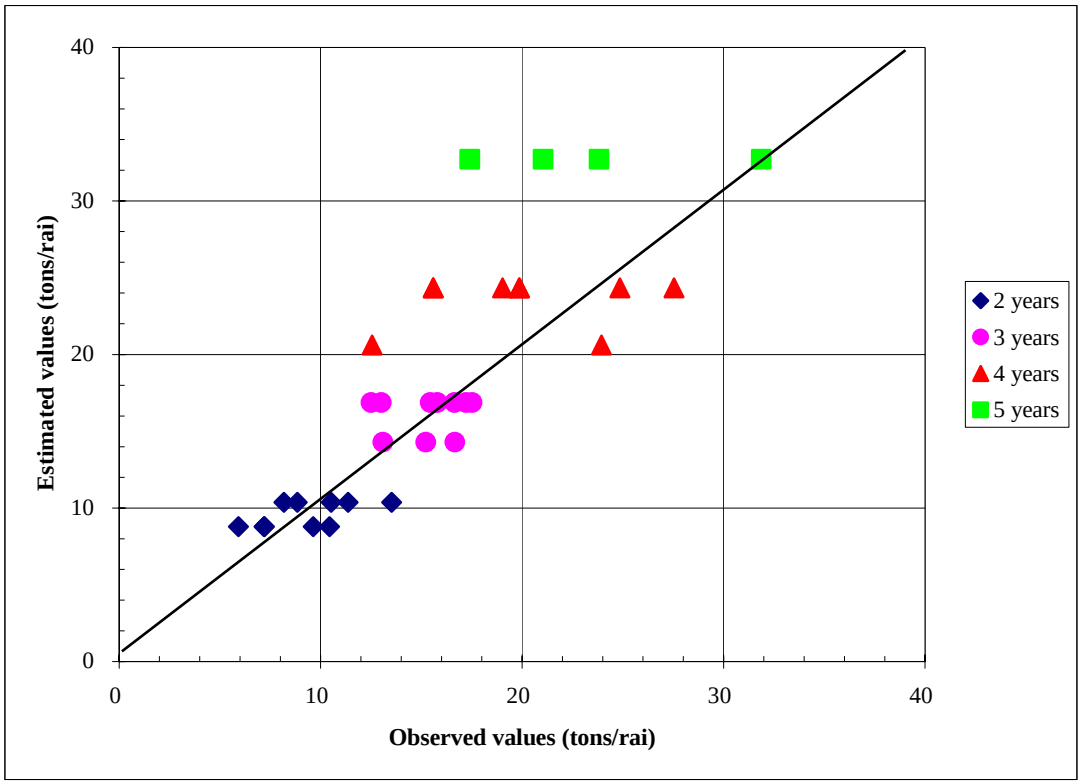


Figure 23 Scatter diagram of the relationship between observed and estimated values of economic production of eucalypt plantation on different site qualities in Chachoengsao province.

Successful decision making to maximize economic profits of the plantation investment generally requires reliable, versatile, and efficient methods for predicting the harvesting yield of wood products in relation to site conditions and stand management. Simple process-based models have attracted increasing interest as an integrated tool or as a component of a sophisticated management information system. Prediction of eucalypt plantation yield in the present study was based primarily on simple growth model in relation to site quality index. Eucalypt plantation yield generally depends not only on site potential but also on suitable planting materials and plantation management as discussed earlier. Consequently, the 3-PG model, from which climatic factors, site conditions and physiological characteristics of the species are modeled, has been widely applied for both softwood and hardwood plantations in

many countries (Landsberg *et al*., 2003). Fundamentally, site parameters in 3-PG include features of soil environment (e.g. fertility, moisture availability, salinity) as well as stand management (e.g. initial stocking, irrigation, fertilizer application). Recently, Morris and Bakker (2003) had developed a process-based model to estimate eucalypt productivity in southern China based on the 3-PG model. Such a model included special forms of some parameters essential for the rapid early growth, high stand density, and short rotations adoped for woodchip production.

However, the DSS developed in the present study was designed to be flexible and able to update some system database for future uses and development. Development of a growth model that integrated site potential, climatic data and physiological characteristics as well as stand management is, therefore, essential to improve the accuracy and reliability of the growth/yield prediction in decision-making of eucalypt plantation investment for future uses in Chachoengsao province as well as in other planting areas by modifying the related system database.

CONCLUSION AND RECOMMENDATION

Conclusion

The DSS development for investment of eucalypt plantation can be separated into four main parts, i.e. system database design and analysis, DSS procedure, user interface design and system output.

Firstly, system database design is a set of database composed of six entities of spatial database, i.e. *subdistrict*, *CCS_SoilSeries*, *LandUse*, *TopoMap*, *Rainfall*, and *Temperature*, and five entities of general database, i.e. *SubDistrict*, *SoilDesc*, *Soilsuit*, *LandUseClassify* and *Financial*. Growth and yield of eucalypt plantations obtained from different soil series were analyzed for classification of site quality. Based on economic production of 3-year rotation, site suitability was classified into four classes, i.e. class 0 unsuitable site, class 1 moderate site quality, class 2 good site quality, and class 3 very good site quality. The economic production of 3-year-old eucalypt stands in form of fresh weight per unit land area on the very good, good, and moderate site qualities ranged from 110.78 - 129.20, 92.45 – 110.78 and 74.13 - 92.45 t ha^{-1} or 17.72 - 20.67, 14.79 - 17.72 and 11.86 - 14.79 t rai^{-1}, respectively. In addition, cost benefit analysis in terms of B/C ratio and NPV was carried out to recommend users whether the investment of eucalypt plantation is economically worthwhile. The findings suggested that, for all site qualities, the investments of eucalypt plantation were economically profitable after 3 years and even more worthwhile for longer rotations as the tending costs were minimal after a few years of establishment.

Secondly, DSS procedure was constructed using a hierarchical approach to clarify the choice situation and site suitability of the user-defined location in the form of True (T) and False (F). The top of the hierarchy involves input data for the system to specify whether the user-defined location falls into a given choice situation step by step and detailed information is provided accordingly.

Thirdly, management system of user interface was designed according to the user-friendly interactive concept for simplicity and high information content including welcome homepage, data input page, interactive pages, output pages. The Thai system language was, therefore, applied to simply communicate with Thai entrepreneurs and farmers.

Lastly, DSS output can be summarized into 3 categories, i.e. preliminary, financial, and summary reports. Particularly, in order to meet all specific objectives of the DSS for eucalypt plantation investment, summary report output page was designed to briefly provide all information needed for decision making as follows: (1) general information of the defined area; (2) wood production and benefits; (3) aggregate costs throughout the plantation management program; and (4) financial analysis.

Recommendation

1. The DSS developed in the present study was designed to be flexible and able to update some system database for future uses and development.

2. Development of a growth model that integrated site potential, climatic data and physiological characteristics as well as stand management is, therefore, essential to improve the accuracy and reliability of the growth/yield prediction in decision making of eucalypt plantation investment in the study area for future uses.

3. The DSS developed in the present study could be implemented to other planting areas by modifying the related system database.

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APPENDIX

Description of soil series in Chachoengsao province

Soil name:	**Bang Pakong series : Bpg**
Classification:	a) National: Hydromorphic alluvial soils
	b) USDA: Typic hydraquents
Described by:	-
Date:	-

I. INFORMATION OF THE SITE

Location:	Khlong Dan, Amphoe Bang Bo, Samut Prakan Province
Elevation:	1 m
Relief and slope:	Flat
Physiography:	Tidal flat
Natural vegetation or land Use:	Mangrove forest
Climate:	a) Climate type: Tropical savanna and tropical monsoon
	b) Annual rainfall: 1314.6 mm
	c) Mean temperature : 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Recent marine sediments
b. Drainage:	Very poorly drained
c. Permeability:	Moderate due to the presence of root channels and crab holes
d. Run off:	Slow
e. Ground water depth:	At or near the surface throughout the year
f. Other:	-

III. SOIL TAXONOMY

Order:	Entisols
Suborder:	Aquents
Great groups:	Sulfaquents
Subgroup:	Typic
Family:	Fine, Smectitic, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	Acid
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	-

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ag	0-5	Brown (7.5YR4/2) nearly ripe clay; many coarse dark gray mottles; mildly alkaline (field pH 7.5).
ACg	5-30	Dark gray (10YR4/1) half ripe clay; few fine distinct brown mottles along root channels; many fine roots; moderately alkaline (field pH 8.0).
Cg1	30-100	Dark gray (5Y4/1) nearly unripe clay; many fine fibrous and few coarse roots, partly decomposed roots; strongly alkaline (field pH 8.5).
Cg2	100-160^{+}	Dark greenish gray (5GY4/1) and dark gray (5Y4/1); nearly unripe clay; strongly alkaline (field pH 8.5).

Soil name:	**Bang Nam Priew series : Bp**
Classification:	a) National : Hydromorphic Alluvial Soils
	b) USDA : Tropaqu epts
Described by:	van der Kevie and Chalaeo Changprai
Date:	27 May 1969

I. INFORMATION OF THE SITE

Location:	Ban Khlong Sam Bueng Yai, Min Buri, Bangkok
Elevation:	2 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land Use:	Broadcasted rice
Climate:	a) climate type: Tropical savanna
	b) Annual rainfall: 1,244.2 mm
	c) Mean temperature: 27.6 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Brackish water sediment underlain by marine sediments
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.6 m during the peak of the dry season
f. Other:	-

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	Aquerts
Great groups:	Dystraquerts
Subgroup:	Sulfaqueptic
Family:	Very-fine, mixed, isohyperthermic
Cation exchange capacity:	Active (0.42)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-23	Mixed dark gray (10YR4/1) and very dark gray (10YR3/1) clay; common fine distinct strong brown (7.5YR5/8) mottles; moderate medium angular blocky structure: hard; common fine roots; moderately acid (field pH 6.0); clear, smooth boundary.
ABg	23-54	Dark gray (10YR4/1) and very dark gray (10YR3/1) with large inclusions of very dark grayish brown (10YR3/2) clay; common fine distinct strong brown (7.5YR5/8) mottles; weak prismatic breaking to subangular blocky structure: very firm; common very fine roots; strongly acid (field pH 5.5); clear, wavy boundary.
Bssjg	54-96	Grayish brown (10YR5/2) clay; many medium and coarse distinct strong brown (7.5YR5/8), brownish yellow (10YR6/8) and common fine straw yellow mottles mainly on ped faces; weak prismatic breaking to subangular blocky structure; very firm; thick continuous humus clay coatings in vertical pores; some large black spots of A material; few very fine roots; few iron pipes; extremely acid (field pH 4.0); clear, wavy boundary.
Bssg	96-114	Grayish brown (10YR5/2) clay; common medium prominent yellowish red (5YR4/6) and yellowish brown (10YR5/6) mottles, the latter in vertical pores; moderate medium prismatic structure: sticky, plastic; thick continuous clay coatings in vertical pores; some thin sand layers; very few very fine roots; slightly acid (field pH 6.5); clear, smooth boundary.
BCg	114-160	Grayish brown (10YR5/2) clay; common coarse distinct slightly hard light olive brown (2.5YR5/4) mottles and dark reddish brown (5YR3/3) coatings in root channels; weak coarse subangular blocky structure: sticky, plastic; neutral (field pH 7.0); gradual, smooth boundary.
Cg1	160-200	Dark greenish gray (5GY4/1) clay; common medium faint grayish green(5G4/2), few reddish brown and common slightly hard dark reddish brown(5YR3/3) mottles in pores and on ped faces; weak medium prismatic breaking to medium angular blocky structure: sticky, plastic; thick hard iron coatings in medium pores; moderately alkaline (field pH 8.0).
Cg2	200-280^{+}	Dark greenish gray (5GY4/1) clay; completely reduced and half ripe.

Soil name:	**Bangkok series : Bk**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	Kevie, Thumrong and Cowie
Date:	27 June 1968

I. INFORMATION OF THE SITE

Location:	Ban Khlong Chuad Lak Khao, Amphoe Bang Pli, Samut Prakarn Province
Elevation:	1 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land use:	Transplanted rice with few bushes
Climate:	a) climate type: Tropical savanna and tropical monsoon
	b) Annual rainfall: 1496.8 mm
	c) Mean temperature: 27.8 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Alluvial marine clay
b. Drainage:	Poorly
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Below 1 m in the peak of dry season
f. Other:	Deep wide cracks (1.5-2 cm) up to 1 m depth

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	Aquerts
Great groups:	Endoaquerts
Subgroup:	Ustic
Family:	Very-fine,Smectitic,Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Mollic
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg1	0-12	Very dark gray (10YR3/1) clay; many fine prominent strong brown (7.5YR5/8) mottles mainly along root channels; weak coarse subangular blocky structure to massive; very hard; common very fine roots; moderately acid (field pH 6.0); gradual, smooth boundary.
Apg2	12-30	Black (10YR2/1) to very dark gray (10YR3/1) clay; common fine prominent strong brown (7.5YR5/8) mottles along root channels and coarse on ped faces, few coarse, medium yellowish brown (10YR5/8) mottles; weak coarse angular blocky structure; very firm; slightly acid (field pH 6.5); gradual, smooth boundary.
Bssg1	30-48	Mixed very dark gray (10YR3/1), dark gray (5Y4/1), olive gray (5Y4/2) clay; many coarse prominent yellowish brown (10YR5/8) mottles; weak coarse angular blocky structure; firm; few big slickensides; neutral (field pH 7.0); gradual, smooth boundary.
Bssg2	48-90	Gray (5Y5/1) few very dark gray (10YR3/1) inclusions, clay; many coarse and medium prominent yellowish brown (10YR5/8), strong brown (7.5YR5/8) and few coarse distinct very dark brown (10YR2/2) mottles; moderate coarse angular blocky structure; firm; common big slickensides; clay coatings in pores; possibly Mn; neutral (field pH 7.0); gradual, smooth boundary.
Bg	90-130	Gray (5Y5/1) nearly ripe clay; many fine and medium prominent yellowish brown (10YR5/8), distinct light olive brown (2.5Y5/4), few very coarse very dark brown (10YR2/2) mottles include small, slightly hard iron pipes, most of the mottles occur along root channels and few coarse prominent black mottles; moderate coarse angular blocky structure; sticky, plastic; neutral (field pH 7.0); gradual, smooth boundary.
BCg	130-140	Dark gray (5Y4/1) half ripe clay; many prominent yellowish brown (10YR4/4), distinct olive brown (2.5Y4/4), dark greenish gray (5GY4/1) mottles mainly along root channels, inside of root channel is still reduced greenish mottles increase with depth; weak coarse prismatic breaking to moderate fine angular blocky structure; sticky, plastic; moderately alkaline (field pH 8.0); gradual boundary.
Cg1	140-200	Dark gray (5Y4/1) nearly unripe clay; many medium distinct dark greenish gray (5GY4/1) mottles which become greener with depth (near 5G4/1) and few dark olive brown mottles; moderately alkaline (field pH 8.0).
Cg2	200-320	Dark greenish gray (5GY4/1), the matrix color becomes slightly greener with depth (near 5G4/1) nearly unripe clay; moderately alkaline (field pH 8.0).

Soil name:	**Cha-am series : Ca**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	van der Kevie and Chalaeo Changprai
Date:	25 April 1969

I. INFORMATION OF THE SITE

Location:	Amphoe Bang Prakong, Chachoengsao Province
Elevation:	2.5 m
Relief and slope:	Flat, slope 0-1 %
Physiography:	Former tidal flat
Natural vegetation or land use:	Transplanted and broadcast rice
Climate:	a) climate type: Tropical Savanna
	b) Annual rainfall: 1314.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Brackish over marine sediments
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.5 m during the peak of dry season
f. Other:	Cracks of 4 mm wide down to 40 cm

III. SOIL TAXONOMY

Order:	Inceptisols
Suborder:	Aquepts
Great groups:	Sulfaquepts
Subgroup:	Typic
Family:	Very-fine, mixed, isohyperthermic
Cation exchange capacity:	Semiactive (0.38)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-19	Dark grayish brown (10YR4/2) heavy clay; few fine distinct strong brown(7.5YR5/8) mottles, mainly along root channels; weak medium prismatic breaking to coarse subangular blocky structure; firm, sticky, plastic; many fine and few medium roots; very strongly acid (field pH 4.5); clear, slightly wavy boundary.
Bag	19-46	Grayish brown (10YR5/2) heavy clay; many fine and medium prominent yellowish red (5YR4/6-8) mottles, mainly as coatings in root channels and on ped faces; moderate weak medium and coarse subangular blocky structure; firm, sticky, plastic; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bjg1	46-90	Grayish brown (10YR5/2) heavy clay; many medium and few coarse distinct pale yellow (2.5Y7/4) mottles, mainly filling in coarse root channels and on ped faces; moderate weak angular and subangular blocky structure; slightly firm, sticky, plastic; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bjg2	90-120	Dark gray to gray (5Y4-5/1) heavy clay; many coarse prominent dark reddish brown (5YR3/3) and reddish brown (5YR4/4) mottles only as coatings on vertical ped faces, few medium and coarse prominent pale yellow (2.5Y7/4) mottles, only very thin coatings on vertical ped faces; moderate coarse angular blocky structure; sticky, plastic; very strongly acid (field pH 5.0); gradual, smooth boundary.
Cg1	120-150	Dark greenish gray (5GY4/1) nearly ripe clay; few dark reddish brown; iron coatings in vertical medium pores; sticky, plastic; slightly hard iron coatings on vertical ped faces; moderately alkaline (field pH 8.0); gradual, smooth boundary.
Cg2	150-200	Dark greenish gray (5GY4/1) half ripe clay; at 100 cm; a thin silty clay layer of 3 cm thick with firm consistence; color close to 5GY5/1; moderately alkaline (field pH 8.0).

Soil name:	**Chachoengsao series : Cc**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	S. Panichapong and P. Vijarnsorn
Date:	22 January 1981

I. INFORMATION OF THE SITE

Location:	50 meters, east of Highway No.121, Ban Khlong Lad Khwang, Amphoe Ban Pho, Chachoengsao Province
Elevation:	3 m
Relief and slope:	Flat, no slope
Physiography:	Old tidal flat
Natural vegetation or land use:	Transplanted rice
Climate:	a) climate type: Tropical Savanna
	b) Annual rainfall: 1,244.2 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Alluvial brackish water
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.5 m during the peak of dry season
f. Other:	-

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	aquerts
Great groups:	Dystraquerts
Subgroup:	Ustic
Family:	Fine, mixed, isohyperthermic
Cation exchange capacity:	Semiactive(0.34)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-22	Dark gray to very dark gray (10YR3-4/1) clay; many fine prominent yellowish red (5YR5/8) mottles along root channels; weak coarse blocky to massive; firm, very sticky, very plastic; many fine roots; strongly acid (field pH 5.5); clear, smooth boundary.
Cg1	125-165	Gray to dark gray (5Y4-5/1) half ripe clay; few decayed roots in places; moderately alkaline field pH 8.0).
Cg2	165-265	Dark greenish gray (5GY4/1) unripe silty clay loam; few decayed roots (in places); common fine shell fragments; moderately alkaline (field pH 8.0).
Bssg	42-70	Grayish brown to brown (10-7.5YR5/2) clay; many medium distinct strong brown (7.5YR5/8), yellowish red (5YR5/8) and few fine prominent red (10R4/8) mottles; massive; very sticky, very plastic; few fine roots; patchy organic matter coatings along cracks, root channels and animal holes; distinct slickensides; neutral (field pH 7.0); clear, irregular boundary.
BCg	70-125	Grayish brown (10YR5/2) clay; many medium distinct strong brown (7.5YR5/8) and prominent yellowish red (5YR5/8) mottles, few spots of jarosite (10YR8/8); massive; very sticky, very plastic; few decay large roots (in places); patchy organic matter coatings along decayed root channels; neutral (field pH 7.0); abrupt, irregular boundary.
Bg	22-42	Dark gray (10YR4/1) clay; many fine distinct strong brown (7.5YR5/8) and few fine prominent yellowish red (5YR5/8) mottles; massive; very sticky, very plastic; common fine roots; patchy organic matter coatings along cracks; strongly acid (field pH 5.5); gradual, smooth boundary.

Soil name:	**Don Muang series : Dm**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	Kevie/Sanan/Preecha
Date:	8 April 1970

I. INFORMATION OF THE SITE

Location:	Amphoe Bang Khen, Bangkok
Elevation:	2 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land use:	Transplanted rice
Climate:	a) climate type: Tropical Savanna
	b) Annual rainfall: 1,000-1,400 mm
	c) Mean temperature: 27 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Sandy brackish water deposits
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.5 m during the peak of dry season
f. Other:	-

III. SOIL TAXONOMY

Order:	Inceptisols
Suborder:	Aquepts
Great groups:	Endoaquepts
Subgroup:	Sulfic
Family:	Fine-loamy,Mixed,Isohyperthermic
Cation exchange capacity:	Semiactive(0.34)
Soil reaction:	Acid
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-26	Brown (7.5YR4-5/2) clay loam; common fine distinct yellowish red (5YR5/8) mottles along root channels; weak coarse subangular blocky structure; firm, sticky, plastic; many fine roots; strongly acid (field pH 5.0-5.5); abrupt, smooth boundary.
Bg	26-53	Pinkish gray (7.5YR6/2) clay loam; common to many fine prominent red(10R4/8) and few fine distinct strong brown (7.5YR5/8) mottles; weak coarse subangular blocky structure; firm, very sticky, very plastic; common fine roots; extremely acid (field pH 4.0-4.5); clear, irregular boundary.
Bjg1	53-80	Pinkish gray (7.5YR6/2) clay loam; many medium to coarse prominent red (10R5/8) and streaks of strong brown (7.5YR5/8) mottles; few to common fine jarosite (2.5Y8/6) in places; weak coarse blocky to massive; firm, very sticky, very plastic; common fine roots; patchy organic matter coatings along root channels; very strongly acid (field pH 4.5); clear, irregular boundary.
Bjg2	80-120	Pinkish gray (7.5YR6/2) clay loam; common medium to coarse prominent red (10R4/8) in places with streaks of common medium distinct strong brown(7.5YR5/8) mottles and few to common jarosite (2.5Y8/6); massive; very sticky, very plastic; very strongly acid (field pH 4.5); gradual, smooth boundary.
BCjg	120-170	Pinkish gray (7.5YR6/2) clay loam; common medium to coarse distinct strong brown (7.5YR7/8) and few medium prominent red (10R4/8) mottles, few medium jarosite (2.5Y8/6); massive; very sticky, very plastic; very strongly acid (field pH 4.5).
Cg	170-240	Grayish brown (10YR5/2) half ripe clay loam; strongly acid (field pH 5.5).

Soil name:	**Maha Phot series : Ma**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Sulfic Tropaquepts
Described by:	Pramote Hemsrichart and Satira Udomsri
Date:	17 March 1997

I. INFORMATION OF THE SITE

Location:	200 meters, west of Prachin Buri-Si Mahosot Road. Km36,
	Ban Khok Peep, Amphoe Si Mahosot, Prochin Buri
Elevation:	15 m
Relief and slope:	Flat, slope less than 1 %
Physiography:	River basin
Natural vegetation or land use:	Paddy field
Climate:	a) climate type: Tropical Savanna
	b) Annual rainfall: 2,009.3 mm
	c) Mean temperature: 28.4 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	River alluvial over brackish sediments
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.5 m during the peak of dry season
f. Other:	-

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	Aquerts
Great groups:	Dystraquerts
Subgroup:	Ustic
Family:	Very-fine,Mixed,Isohyperthermic
Cation exchange capacity:	Active(0.42)
Soil reaction:	-
Upper diagnostics profile:	Umbric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-18	Black (10YR2/1) silty clay; many medium distinct yellowish brown (10YR5/6) mottles; moderate medium and coarse angular blocky within medium and coarse prismatic structure; very firm, very sticky, very plastic; many very fine and common fine roots; some ash along crack surfaces; strongly acid (field pH 5.5); clear, smooth boundary.
Bssg1	18-61/63	Mixed very dark gray (10YR3/1) and dark gray (10YR4/1) silty clay; common fine prominent red (2.5YR4/8) and distinct yellowish brown (10YR5/6) mottles; moderate medium and coarse angular blocky within medium and coarse prismatic structure; firm, very sticky, very plastic; common very fine roots; some iron pipes; many slickensides and pressure faces; very strongly acid (field pH 4.5); clear, wavy boundary.
Bssg2	61/63-106/110	Light brownish gray (10YR6/2) silty clay; common fine and medium distinct brownish yellow (10YR6/6-8) and many coarse prominent red (2.5YR4/6) mottles; weak medium and coarse angular blocky structure; firm, very sticky, very plastic; many slickensides and pressure faces; some iron pipes, many organic matter, color is very dark gray (10YR3/1), coated on ped faces; very strongly acid (field pH 4.5); clear, wavy boundary.
Bssjg	106/110-154	Grayish brown (10YR5/2) silty clay; common fine distinct pale yellow(2.5Y7/4) mottles; weak medium and coarse prismatic breaking to moderate and coarse angular blocky structure; firm, very sticky, very plastic; some iron pipes; some organic matter, color is very dark gray (10YR3/1), coated on slickensides surfaces; few decay roots; many slickensides and pressure faces; common jarosite; very strongly acid (field pH 4.5); clear, smooth boundary.
Cg	154-180+	Dark gray (5Y4/1) half ripe silty clay; massive; very sticky, very plastic; slightly acid (field pH 6.5).

Soil name:	**Ongkharak series : Ok**
Classification:	a) National : Hydromorphic Alluvial Soils
	b) USDA : Sulfic Tropaquepts
Described by:	S. Panichapong and P. Vijarnsorn
Date:	21 January 1981

I. INFORMATION OF THE SITE

Location:	Khlong No.10, 3 Km to the north of Amphoe Nong Suea, Pathum Thani Province
Elevation:	2 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land use:	Abandoned paddy field
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,244.2 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Brackish water deposits
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.0 m during the peak of dry season
f. Other::	-

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	Aquerts
Great groups:	Dystraquerts
Subgroup:	Sulfaqueptic
Family:	Very-fine,Mixed,Isohyperthermic
Cation exchange capacity:	Semiactive(0.32)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-14	Dark grayish brown (10YR3-4/2) clay; common fine prominent yellowish red (5YR5/8) mottles along root channels; weak medium and coarse subangular blocky structure; extremely hard, very firm, very sticky, very plastic; many fine roots; extremely acid (field pH 4.0); abrupt, smooth boundary.
BAg	14-30	Grayish brown (10YR5/2) clay; many medium to coarse prominent red(10R4/6) and common fine distinct strong brown (7.5YR5/6) mottles; weak medium subangular blocky structure to massive; firm, very sticky, very plastic; common fine roots; patchy organic matter coatings; very strongly acid (field pH 4.5); clear, smooth boundary.
Bssjg	30-60	Grayish brown (10YR5/2) clay; many medium and coarse distinct strong brown (7.5YR5/8) and common medium prominent red (10R4/8) mottles; common fine streaks of jarosite, yellow (2.5YR8/6) at the upper part and few at the lower part of the horizon; massive; very sticky, very plastic; few fine roots; patchy organic matter coatings; distinct slickensides; extremely acid(field pH 4.0); diffuse, smooth boundary.
Bjg	60-115	Brown (7.5YR5/2) clay; many medium distinct strong brown (7.5YR5/8) and few fine prominent red (10 R4/8) mottles (streaks); many medium streaks of jarosite, yellow (2.5Y8/6); massive; very sticky, very plastic; few fine roots; extremely acid (field pH4.0); clear, smooth boundary.
BCg	115-165	Brown (7.5YR5/2) clay; few fine discinct yellowish brown (10YR5/4) mottles; few fine jarosite mottles (in places); massive; very sticky, very plastic; few fine decayed roots and other plant residues; extremely acid (field pH 4.0); clear, smooth boundary.
Cg1	165-195	Gray (10YR5/1) nearly ripe clay; few decayed plant residues; very strongly acid (field pH 4.5).
Cg2	195-360	Gray to dark gray (5Y4-5/1) unripe clay; few decayed plant residues; neutral (field pH 7.0).

Soil name:	**Phan Thong series : Ptg**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	Van der Kevie
Date:	23 March 1970

I. INFORMATION OF THE SITE

Location:	Ban Bangna, Amphoe Phan Thong, Chon Buri
Elevation:	3-7 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land use:	Paddy field
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,314.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Marine deposit
b. Drainage:	Poorly drained
c. Permeability:	Moderate
d. Run off:	Slow
e. Ground water depth:	Fall below 1.5 m during the peak of dry season
f. Other::	-

III. SOIL TAXONOMY

Order:	Inceptisols
Suborder:	Aquepts
Great groups:	Endoaquepts
Subgroup:	Mollic
Family:	Fine-silty, Mixed, Isohyperthermic
Cation exchange capacity:	Superactive(0.63)
Soil reaction:	Nonacid
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-10	Very dark gray (10YR3/1) clay; common fine discinct strong brown and prominent reddish yellow mottles in very fine root channels; moderate coarse subangular blocky structure; hard, firm; many fine and very fine roots; slightly acid (field pH 6.5); clear, smooth boundary.
Ag	10-20	Black (10YR2/1) clay; common fine prominent strong brown and reddish yellow mottles in very fine root channels; massive to weak coarse subangular blocky structure; firm, hard; common very fine roots; neutral (field pH 7.0); abrupt, slightly wavy boundary.
2Eg	20-34/40	Light gray to gray (10YR6/1) fine sandy clay loam; very few fine diffuse light olive brown mottles mainly in upper 2 cm of the horizon; weak prismatic; very friable; few thick dark gray and black humus clay coatings on vertical ped faces; black humus clay coatings in vertical pores; few very fine roots; mildly alkaline (field pH 7.5) gradual, wavy boundary.
2Bg1	34/40-70	Light gray to gray (5Y6/1) fine sandy loam; many coarse discinct yellowish brown, strong brown and light olive brown mottles; weak prismatic breaking to coarse subangular blocky structure; friable, slightly sticky; thick black humus clay coatings in vertical pores and on few vertical ped faces; few manganese nodules; few very fine roots; mildly alkaline (field pH 7.5) gradual, wavy boundary.
2Bg2	70-140	Light gray to gray (5Y6/1) fine sandy loam; common medium diffuse light olive brown mottles, few green and olive brown mottles; weak prismatic breaking to subangular blocky structure; friable, slightly sticky; black humus clay coatings in pores; many fine vertical and very fine tubular pores; very few soft manganese nodules; mildly alkaline (field pH 7.5).
2BCg	140-180	Greenish gray (5GY5/1) half ripe clay; few green and olive mottles; some of which are slightly hard; moderately alkaline (field pH 8.0).
2Cg	180-250	Dark greenish gray (5GY4/1) fine sandy loam; very few green mottles; many shell fragments; moderately alkaline (field pH 8.0).

Soil name:	**Rangsit series: Rs**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Sulfic Tropaquepts
Described by:	Van der Kevie & Phichai
Date:	28 May 1970

I. INFORMATION OF THE SITE

Location:	Amphoe Nong Suea, Prathum Thani Province
Elevation:	2 m
Relief and slope:	Flat
Physiography:	Old tidal flat
Natural vegetation or land use:	Transplanted rice
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,244.2 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Brackish water deposits
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.0 m during the peak of dry season
f. Other::	Yield 15 tang/rai with fertilizer

III. SOIL TAXONOMY

Order:	Vertisols
Suborder:	Aquerts
Great groups:	Dystraquerts
Subgroup:	Sulfaqueptic
Family:	Very-fine, Mixed, Isohyperthermic
Cation exchange capacity:	Semiactive(0.40)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-15	Very dark gray to very dark grayish brown (10YR3/1-2) clay; common fine distinct yellowish brown (10YR5/8) mottles mainly along root channels; weak medium and coarse breaking to medium and fine subangular blocky structure; firm, sticky, plastic; many very fine roots; very strongly acid (field pH 5.0); gradual, slightly wavy boundary.
Bssg1	15-30/35	Black (10YR2/1) clay; many fine, medium distinct yellowish brown (10YR5/8) and few fine prominent red (2.5YR4/8) mottles; weak to moderate breaking to fine angular blocky structure; firm, sticky, plastic; few slickensides; few very fine roots; very strongly acid (field pH 4.5); gradual, wavy boundary.
Bssg2	30/35-49	Mixed very dark grayish brown (10YR3/2) and grayish brown (10YR5/2) clay; many medium and coarse prominent red (10R4/8, 7.5R3/8), fine and medium distinct yellowish brown (10YR5/8) mottles; moderate medium and fine angular blocky structure, firm, sticky, plastic; few very fine roots; common pressure faces and slickensides; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bssjg1	49-59/65	Brown (7.5YR5/2) clay; few small inclusion of dark A materials; many medium and coarse prominent red (2.5YR4/8) and dark red (7.5R3/8) and many fine pale yellow (2.5YR7/4) (jarosite mottles) and few fine yellowish brown(10YR5/8) mottles; moderate medium and fine angular blocky structure; firm, sticky, plastic; few very fine roots; common pressure faces and slickensides; very strongly acid(field pH 4.5); clear, wavy boundary.
Bssjg2	59/65-110	Brown (7.5YR5/2) clay; many medium and coarse pale yellow (2.5Y8/6) (jarosite) and few fine distinct yellowish brown (10YR5/8) mottles as vertical streaks; moderate prismatic breaking to angular blocky structure; firm, sticky, plastic; few slickensides; very strongly acid (field pH 4.5).
Cjg	110-160	Brown (7.5YR5/2) half ripe clay; common medium and coarse distinct yellowish brown (10YR5/8) and few medium pale yellow (2.5Y8/6) mottles; very strongly acid (field pH 4.5).
Cg	160-190+	Dark greenish gray (5GY4/1) and dark gray (5Y4/1) half ripe clay; moderately acid (field pH 6.0).

Soil name:	**Samut Prakan series: Sm**
Classification:	a) National: Hydromorphic Alluvial Soils
	b) USDA: Typic Tropaquepts
Described by:	C. Navanugraha, P.Vijarnsorn and W.Sirichauychoo
Date:	27 May 1983

I. INFORMATION OF THE SITE

Location:	1 Km, west of Ban Don Mai, Tambon Hat Chao Samran, Amphoe Mueang, Phetchaburi Province
Elevation:	0.5-1.0 m
Relief and slope:	Flat, slope 1 % or less
Physiography:	Former tidal flat
Natural vegetation or land use:	Paddy field
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,044.1 mm
	c) Mean temperature: 27.6 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Brackish water sediment
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	Fall below 1.0 m during the peak of dry season
f. Other:	-

III. SOIL TAXONOMY

Order:	Inceptisols
Suborder:	Aquepts
Great groups:	Endoaquepts
Subgroup:	Fouvaquentic
Family:	Fine, Smectitic, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	Nonacid
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Cambic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-25	Gray (10YR5/1) and dark gray (10YR4/1) clay; weak fine and medium prismatic structure; hard, very firm, sticky, plastic; common very fine and fine roots; slightly acid (field pH 6.5); clear, smooth boundary.
Bg1	25-46	Gray (5Y5/1) clay; many fine discinct dark gray (2.5Y4/1) and olive brown(2.5Y4/4) mottles; moderate fine and medium angular and subangular blocky structure; firm, sticky, plastic; few very fine roots; many pressure faces in cracking channels and black color coated on some cracking channels; moderately alkaline (field pH 8.0); clear, smooth boundary.
Bg2	46-75	Gray to dark grayish brown (2.5Y5/1-2) clay; common fine distinct olive brown (2.5Y4/4) and brown (10YR4/3) mottles; moderate fine and medium angular and subangular blocky structure; firm, sticky, plastic; few fine and medium roots black color coated in cracking channel; moderately alkaline (field pH 8.0); clear, smooth boundary.
Cg1	75-105	Olive gray to light olive gray (5Y5-6/2) half ripe clay; massive; very sticky, very plastic; common fine soft iron nodules and few decay roots and some pieces of wood; moderately alkaline (field pH 8.0); abrupt, smooth boundary.
Cg2	105-140	Gray (5Y5/1) sand; many fine prominent dark yellowish brown (10YR4/4) mottles; single grain; nonsticky, nonplastic; few fine soft iron pipes; moderately alkaline (field pH 8.0); clear, smooth boundary.
Cg3	140-165	Dark greenish gray (5BG4/1) sandy loam; single grain; slightly sticky, nonplastic; few weathered shell fragments; moderately alkaline (field pH 8.0)
Cg4	165-200	Dark greenish gray (5BG4/1) unripe clay; massive; slightly sticky, slightly plastic; moderately alkaline (field pH 8.0)

Soil name:	**Bang Khla series: Bka**
Classification:	a) National: Red Yellow Podzolic
	b) USDA: Typic Paleustults
Described by:	Vichan Thongmee
Date:	17 January 1977

I. INFORMATION OF THE SITE

Location:	Amphoe Bang Khla, Chachoengsao Province
Elevation:	22 m
Relief and slope:	Undulating, 2 %
Physiography:	Terrace deposit
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: -
	c) Mean temperature: -

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	Fall below 1.2 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-12	Mixed very dary grayish brown (10YR 3/2) and yellowish brown (10YR 6/4) sandy loam; moderate fine and medium subangular blocky structure; slightly hard, non sticky, non plastic; common fine and few medium roots; strongly acid clear, smooth boundary; pH 5.5
B1	12-30	Brown (7.5YR 5/4) sandy loam; moderate fine and medium subangular blocky structure; slightly hard, slightly sticky, slightly plastic; patchy thin clay coating on ped faces, common fine and few medium roots; very strongly acid clear smooth boundary; pH 5.0
B21tcn	30-45/52	Brown (7.5YR 5/4) gravelly sandy clay loam; hard, sticky, plastic; patchy thin clay coating on ped faces, common very fine and few fine roots; many Fe/Mn concretion about 35 % by volume; very strongly acid diffuse, wavy boundary; pH 5.0
B22tcn	45/52-90	Yellowish red (5YR 5/6) very gravelly sandy clay loam; hard, sticky, plastic; broken moderately thick clay coating on ped faces and continuous moderately thick in pores; few very fine roots; gravels composed of Fe/mn concretion about 60 % of soil matrix; very strongly acid (pH 4.5)

Soil name:	**Bang Khla, brown variant: Bka-br**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Typic Paleustults
Described by:	Chavalit Karnjanaserm
Date:	12 May 1976

I. INFORMATION OF THE SITE

Location:	Ban Hin Rae, Amphoe Sanam Chai Khet, Chachoengsao Province
Elevation:	50 m
Relief and slope:	Slightly undulating, 1-2 %
Physiography:	Middle terrace
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium to slow
e. Ground water depth:	Fall below 55 cm
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A1	0-6	Brown (7.5YR 5/2) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common very fine and fine roots; clear, smooth boundary; pH 6.5
B1	6-18	Brown (7.5YR 5/4) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common very fine and few coarse roots; gradual, smooth boundary; pH 6.0
B21	18-42	Light brown to reddish yellow (7.5YR 6/4-6/6) gravelly sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic, patchy thin clay coating on ped faces, few very fine, fine and medium roots, clear wavy boundary; pH 5.0
B22	$42\text{-}55^{+}$	Light brown to reddish yellow; gravelly (7.5YR 6/4-6/6) sandy loam; slightly sticky, slightly plastic, very few very fine and fine roots; pH 5.0

Soil name:	**Chon Buri series : Cb**
Classification:	a) National: Low Humic Gley Soils
	b) USDA: Paleaqualfs
Described by:	Somkid Phothong, et. al.
Date:	25 May 1981

I. INFORMATION OF THE SITE

Location:	Ban Napla, Amphoe Muang, Chon Buri
Elevation:	10-40 m
Relief and slope:	Flat
Physiography:	Terrace deposit
Natural vegetation or land use:	Transplanted rice
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,450 mm
	c) Mean temperature: 27 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Somewhat poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	More than 150 cm
f. Other::	-

III. SOIL TAXONOMY

Order:	Alfisols
Suborder:	Aqualfs
Great groups:	Endoaqualfs
Subgroup:	Typic
Family:	Fine-loamy, Mixed, Isohyperthermic
Cation exchange capacity:	Superactive (CEC/clay = 0.22)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-17	Grayish brown to brown (10YR5/2-3) sandy loam; common fine distinct dark yellowish brown (10YR4/6) mottles; weak fine subangular blocky structure; friable, nonsticky and nonplastic; common fine roots; slightly acid (field pH 6.5); gradual smooth boundary.
BAg	17-32	Light brownish gray (10YR6/2) sandy loam; few fine faint light yellowish brown (10YR6/4) mottles; weak fine subangular blocky structure; friable, slightly sticky and slightly plastic; few very fine roots; moderately alkaline (field pH 8.0); gradual smooth boundary.
Btg1	32-62	Light brownish gray (10YR6/2) sandy clay loam; few fine faint yellowish brown (10YR5/8) and common medium distinct strong brown (7.5YR5/8) mottles; strong medium and coarse subangular blocky structure; firm, slightly sticky and slightly plastic; patchy thin clay coating on ped faces; few fine roots; moderately alkaline (field pH 8.0); gradual smooth boundary.
Btg2	62-85	Light brownish gray to pale brown (10YR6/2-3) and krotovina of grayish brown (10YR5/2) sandy clay loam; few fine distinct strong brown (7.5YR5/6) mottles; moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; patchy thin clay coating on ped faces; few fine roots; few of manganese oxides; moderately alkaline (field pH 8.0); gradual smooth boundary.
Btg3	85-100	Dark brown to brown (7.5YR4-5/2, color of sand) sandy clay loam; common medium distinct strong brown (7.5YR5/8) and few fine prominent red (2.5YR4/8) mottles; moderate fine subangular blocky structure; firm, slightly sticky and slightly plastic; patchy thin clay coating on ped faces; few fine roots; few of manganese oxides and iron stones; strongly alkaline (field pH 8.5); clear smooth boundary.
Btg4	100-150	Light brownish gray (10YR6/2) sandy clay loam; few medium distinct strong brown (7.5YR5/6) and few fine faint yellowish brown (10YR5/6) mottles; moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; patchy thin clay coating on ped faces; few fine roots; few of manganese oxides; strongly alkaline (field pH 8.5).

Soil name:	**Don Rai series: Dr**
Classification:	a) National: Gley Podzolic Soils
	b) USDA: Paleustults
Described by:	Noi & Supat
Date:	24 April 1977

I. INFORMATION OF THE SITE

Location:	Ban Hui Hin
Elevation:	40 m
Relief and slope:	Undulating, 3 %
Physiography:	terrace deposit
Natural vegetation or land use:	cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: -
	c) Mean temperature: -

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Moderately well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	More than 100 cm
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Kandiustults
Subgroup:	Typic
Family:	Fine-loamy, Kaolinitic, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Kandic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-16	Dark grayish brown (10YR3/3) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; many fine and medium roots; slightly acid (field pH 6.5); clear, slightly wavy boundary.
Bt1	16-32	Brown (7.5YR4/2) sandy loam; common medium distinct strong brown(7.5YR5/8) mottles; moderate medium and coarse subangular blocky structure; firm, slightly sticky, slightly plastic; patchy thin clay coatings on ped faces, few fine and medium roots; slightly acid (field pH 6.5); clear, smooth boundary.
Bt2	32-49	Brown (7.5YR5/2) sandy clay loam; many medium distinct yellowish brown (10YR5/6) mottles; very firm, sticky, plastic; patchy thin clay coatings on ped faces and continuous moderately thick in pores; few medium animal holes; few medium roots; slightly acid (field pH 6.5); gradual, smooth boundary.
Bt3	49-81	Brown (10YR5/3) heavy sandy clay loam; many medium and coarse prominent yellowish red (5YR5/8) mottles; strong medium and coarse subangular blocky structure; sticky, plastic; patchy thin clay coatings on ped faces and continuous thick in pores; few charcoal pieces and many fine animal holes; one medium roots; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bt4	81-110+	Pale brown (10YR6/3) sandy clay; many medium yellowish red (5YR5/8) and few fine distinct reddish yellow (7.5YR6/8) mottles; moderate medium and coarse subangular blocky structure; firm, sticky, plastic; patchy thin clay coatings on ped faces and continuous moderately thick in pores; few medium and few large roots; very strongly acid (field pH 4.5).

Soil name:	**Hin Kong series: Hk**
Classification:	a) National: Low Humic Gley Soils
	b) USDA: Aeric Paleaquults
Described by:	Satira Udomsri
Date:	21 April 1998

I. INFORMATION OF THE SITE

Location:	200 Meters, west of Ban Na-Saraburi road, Ban Rai Pho Hak, Amphoe Ban Na, Nakhon Nayok
Elevation:	15 m
Relief and slope:	flat, slope 1 %
Physiography:	low terrace
Natural vegetation or land use:	paddy field
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 2,009.3 mm
	c) Mean temperature: 28.4 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Semi-recent alluvium
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	>2 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Aquults
Great groups:	Paleaquults
Subgroup:	Typic
Family:	Fine-silty, Mixed, Isohyperthermic
Cation exchange capacity:	Subactive(0.23)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-15/18	Mixed white and light gray (10YR8/1 and 10YR7/2) silt loam; common fine and medium distinct brownish yellow (10YR6/8) mottles; moderate weak fine and medium subangular blocky structure; slightly hard, friable, sticky, slightly plastic; common very fine and fine roots; moderately acid (field pH 6.0); clear, wavy boundary.
Bg	15/18-28	Mixed white and light gray (10YR8/1 and 10YR7/2) silt loam; many medium and coarse distinct brownish yellow (10YR6/6-8) mottles; moderate medium and coarse subangular blocky structure; slightly hard, friable, sticky, plastic; common very fine and fine roots; strongly acid (field pH 5.5); clear, smooth boundary.
Btg1	28-44	Mixed white and pale brown (10YR8/1 and 10YR6/3) silt loam; many medium and coarse distinct brownish yellow (10YR6/8), few fine distinct strong brown (7.5YR4/6) mottles; strong medium and coarse subangular blocky structure; hard, friable, sticky, plastic; patchy moderately thick cutan on ped faces and in pores; few very fine roots; few to common soft black Fe&Mn concretions; very strongly acid (field pH 5.0); clear, smooth boundary.
Btg2	44-82/86	Grayish brown (10YR5/2) silty clay loam; common medium distinct brownish yellow and yellowish brown (10YR6/8 and 10YR5/6) mottles; strong medium and coarse subangular blocky structure; very hard, firm, sticky, plastic; patchy moderately thick cutan on ped faces and in pores; common soft black Fe&Mn concretions; very strongly acid (field pH 5.0); clear, wavy boundary.
Btg3	82/86-140	Light brownish gray (10YR6/2) silty clay loam; many medium and coarse distinct pale brown and yellowish brown (10YR6/3 and 10YR6/8) mottles; strong medium and coarse subangular blocky structure; very hard, firm, very sticky, very plastic; patchy moderately thick cutan on ped faces and in pores; some organic mater coated on ped faces; strongly acid (field pH 5.5); clear, smooth boundary.
Btg4	140-200	Grayish brown (10YR5/2) silty clay loam; common fine and medium distinct yellowish brown (10YR6/8) mottles; strong coarse subangular blocky structure; slightly hard, firm, very sticky, very plastic; patchy moderately thick cutan on ped faces and in pores; strongly acid (field pH 5.5).

Soil name:	**Klaeng series: Kl**
Classification:	a) National: Low Humic Gley Soils
	b) USDA: Oxic Plinthaquults
Described by:	Kevie, Chalieo
Date:	23 April 1969

I. INFORMATION OF THE SITE

Location:	Chachoengsao Province
Elevation:	10-20 m
Relief and slope:	Low terrace, flat
Physiography:	Level terrain of the lower portion of low terrace
Natural vegetation or land use:	Transplanted rice (20 tang/rai)
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Somewhere poorly drained
c. Permeability:	Estimated to be slow
d. Run off:	Slow
e. Ground water depth:	Below 1.0 m during the peak of dry season.
f. Other:	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Aquults
Great groups:	Plinthaquults
Subgroup:	Typic
Family:	Very-fine, Kaolinitic, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-10	Dark grayish brown (10YR4/2) clay loam; few iron mottles coating along roots channels; moderate medium subangular blocky structure; slightly hard, slightly sticky and slightly plastic; common medium tubular and few medium interstitial pores; many fine and medium roots; very strongly acid (field pH 5.0); clear wavy boundary.
Bg	10-26	Light gray to gray (10YR6/1) clay; many fine prominent yellowish red (5YR5/6) mottles along roots channels; moderate medium and coarse subangular blocky structure; hard, sticky and plastic; black possible humus coating on ped faces and along cracks; few fine tubular and common medium interstitial pores; many fine roots; very strongly acid (field pH 4.5); gradual smooth boundary.
Btg	26-42	Grayish brown (10YR5/2) clay; common medium prominent yellowish red (5YR4/6) and distinct strong brown (7.5YR5/8) mottles; strong medium and coarse subangular blocky structure; very hard, sticky and plastic; common patchy thin cutan on ped faces; few fine tubular pores, common fine and medium interstitial pores; common very fine roots; very strongly acid (field pH 4.5); clear smooth boundary.
Btgv1	42-65	Gray (10YR5/1) clay; many medium and coarse prominent dark red (10R3/6) and strong brown (7.5YR5/6) mottles; moderate fine and medium subangular blocky structure; sticky and plastic; many patchy moderately thick cutan on ped faces; Plinthite (10YR3/6, red) > 50% by volume of the soil matrix or continuous phase; few fine tubular and common fine interstitial pores; few fine roots; very strongly acid (field pH 4.5); clear smooth boundary.
Btgv2	65+	Gray (10YR5/1) clay; many medium and coarse prominent dark red (10R3/6) mottles; moderate fine and medium subangular blocky structure; sticky and plastic; many patchy moderately thick cutan on ped faces; Plinthite (10YR3/6, red) > 50% by volume of the soil matrix or continuous phase; few medium tubular and common fine interstitial pores; very strongly acid (field pH 4.5).

Soil name:	**Ko Khanun series: Kkn**
Classification:	a) National: Low Humic Gley Soils
	b) USDA: Aeric Oxic Plinthaquults
Described by:	Pisoot Vijansorn
Date:	4 May 1975

I. INFORMATION OF THE SITE

Location:	2.5 kmeast of Amphoe Sanam Chai Khet, Tambon Bang Mafuang, Amphoe Sanam Chai Khet, Chachoengsao Province
Elevation:	15 m
Relief and slope:	Nearly flat, slope 1 %
Physiography:	Middle terrace
Natural vegetation or land use:	Mixed deciduous forest
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Relatively old alluvium
b. Drainage:	Somewhere poorly drained
c. Permeability:	Moderate
d. Run off:	Slow
e. Ground water depth:	3.5 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A1	0-7	Dark grayish brown (10YR4/2-4/3) loam; few fine faint dark grayish brown mottles; weak fine and medium subangular blocky structure; friable, slightly sticky slightly plastic; few fine roots; medium acid clear smooth boundary; pH 6.0
A2	7-22	Pinkish gray (5YR 6/2-6/3); fine sandy loam to loam; weak medium subangular blocky structure; friable, slightly sticky slightly plastic; few fine medium roots; strongly acid clear smooth boundary; pH 5.5
B1	22-48	Light reddish brown (5YR 6/4); fine sandy loam to loam; many medium distinct yellowish red mottles; weak medium subangular blocky structure; friable, slightly sticky and plastic; few fine and medium roots; very strongly acid gradual smooth boundary; pH 5.0
B21t	48-73	Light pinkish gray (5YR 6/2); clay loam; many medium prominent yellowish red; moderately medium to coarse subangular blocky structure; friable, sticky and plastic; few fine clay coating; plinthites of red color forming continuous compose of 5-10 % by volume; common fine and medium roots; very strongly acid gradual smooth boundary; pH 5.0
B22t1	73-100	Pinkish gray (5YR 7/2); clay loam; common medium distinct strong brown and dark red mottles; moderately medium subangular blocky structure; friable, sticky and plastic; common fine clay coating; on ped faces plinthites forming as continuous faces; very strongly acid gradual smooth boundary; pH 5.0
B23	100-125	Light gray (5YR 7/1); clay loam; common medium prominent yellowish red mottles; other features almost identical to above horizon except more plinthite.

Soil name:	**Korat series: Kt**
Classification:	a) National: Gley Podzolic Soils
	b) USDA: Oxic Dystropepts
Described by:	R.L. Pendleton
Date:	1929

I. INFORMATION OF THE SITE

Location:	Right of Ban Rung-Ban Don Ao road, Tambon Rueng, Amphoe Kantharalak, Si Sa Ket Province
Elevation:	150-240 m
Relief and slope:	Gently undulating to undulating , slope 2-6 %
Physiography:	Upper part of peneplain
Natural vegetation or land use:	Upland crops
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: -
	c) Mean temperature: 27 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Washed deposit from sandstone
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	>2.0 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Kandiustults
Subgroup:	(Oxyaquic)
Family:	Fine-loamy,Siliceous,Isohyperthermic
Cation **e**xchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Kandic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-19	Dark brown (10YR3/3) sandy loam; moderate fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; many coarse, few medium and fine roots; many pieces of charcoal; few termite holes; very strongly acid (field pH 5.0); clear, smooth boundary.
Bt1	19-61	Brown (10YR5/3) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, slightly sticky, plastic; patchy thin clay coating on ped faces; few very fine and fine roots; few termite holes; very strongly acid (field pH 5.0): gradual, smooth boundary.
Bt2	61-87	Yellowish brown (10YR5/4) sandy clay loam: moderate medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin clay coating on ped faces; few very fine roots; some termite holes; strongly acid (field pH 5.5); gradual, smooth boundary.
Bt3	87-120	Yellowish brown (10YR5/4) sandy clay loam; common fine distinct strong brown (7.5YR5/6) and few fine faint light brownish gray (10YR6/2) mottles; weak fine to medium subangular blocky structure; slightly sticky, plastic; broken moderately thick clay coating on ped faces and in pores; few very fine and medium roots; strongly acid (field pH 5.5); clear, smooth boundary.
Btg	120-150	Pinkish gray (7.5YR6/2) sandy clay loam; common fine and medium distinct strong brown (7.5YR5/6) and common fine prominent red (2.5YR4/6) mottles; weak fine to medium subangular blocky structure; friable, slightly sticky, plastic; broken moderately thick clay coating on ped faces; few rotten roots and few coarse roots; strongly acid (field pH 5.5).

Soil name:	**Nong Khok series: Nkk**
Classification:	a) National: Red Yellow Podzolics
	b) USDA: Oxic Paleustults
Described by:	Udom & Adul
Date:	28 May 1975

I. INFORMATION OF THE SITE

Location:	Ban Nong Khok
Elevation:	90 m
Relief and slope:	Undulating 3 %
Physiography:	Middle terrace
Natural vegetation or land use:	Mixed deciduous
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Somewhere poorly drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	Below 2.0 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A1	0-8	Dark brown (7.5YR 4/4) sandy loam; weak fine subangular blocky structure; very friable, slightly sticky, slightly plastic; common fine tubular and interstitial pores; many fine and few medium roots; clear smooth boundary; slightly acid (pH 6.5)
A2	8-20	Strong brown (7.5YR 5/6) coarse sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, plastic; few very fine and fine tubular pores; common very fine and fine, and few medium roots; clear slightly wavy boundary; slightly acid (pH 6.0)
B1	20-38	Yellowish red (5YR 5/6) coarse sandy loam; moderate medium subangular blocky structure; slightly sticky, slightly plastic; common very fine and fine tubular pores; common very fine and fine roots; clear smooth boundary; medium acid (pH 6.0)
B21t	38-62	Yellowish red (5YR 5/6) gravelly coarse sandy loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin clay coating on ped faces and along pores; about 15 % mostly irregular Fe/Mn concretions and few quartz grains cemented by iron oxides; many fine, common medium interstitial pores; few very fine and fine roots; clear smooth boundary; medium acid (pH 6.0)
B22t	62-90	Yellowish red (5YR 5/8) gravelly coarse sandy loam; slightly sticky, slightly plastic; patchy thin clay coating on ped faces and along pores; about 40 % subrounded and irregular Fe/Mn concretion, quartzite grains and quartzite grains cemented by iron oxides; many very fine and fine, common medium and coarse interstitial pores; few very fine and fine roots gradual smooth boundary; pH 6.0
B23t	90-200	Yellowish red (5YR 5/8) gravelly coarse sandy loam; slightly sticky, slightly plastic; clay coating on ped faces and along pores; about 60 % subrounded and irregular Fe/Mn concretion, quartzite grains and quartzite grains cemented by iron oxides; many fine and medium, and common coarse interstitial pores; few very fine and fine roots; medium acid pH 6.0

Soil name:	**Pang Rai series: Pg**
Classification:	a) National: Red Yellow Podzolic Soil
	b) USDA: Typic Paleudult
Described by:	Chavalit
Date:	January, 1975

I. INFORMATION OF THE SITE

Location:	Ban Tamung, Amphoe Sanam Chai Khet, Chachoengsao Province
Elevation:	46 m
Relief and slope:	Undulating slope 3-4 %
Physiography:	Terrace deposite
Natural vegetation or land use:	Orchard, banana
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	Below 4.0 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-6	Mixed dark brown (7.5YR 3/2) and dark reddish (5YR 3/2) sandy loam; weak fine and medium subangular blocky structure; soft, slightly sticky, slightly plastic; few very fine and fine roots; neutral clear, smooth boundary; pH 6.5
B1	6-32	Yellowish red (5YR 4/8) sandy loam; moderate subangular blocky structure; soft, slightly sticky, slightly plastic; patchy thin clay coating on ped faces and continuous moderately thick in pores, common very fine and few medium roots; strongly acid clear, smooth boundary; pH 6.0
B21t	32-68	Yellowish red (5YR 5/8) gravelly sandy clay loam; slightly hard, sticky, slightly plastic; gravels composed of subrounded ironstone and quartzsite having diameter of 0.5-5 cm broken moderately thick clay coating on ped faces and in pores, few very fine and medium roots; strongly acid (pH 5.5) clear, smooth boundary
B22t	68-100	Red (2.5YR 4/8) very gravelly sandy clay; friable, sticky, plastic, gravels composed of Fe/Mn and rounded and subrounded quartzsite 50 % by volume; broken moderately thick clay coating on ped faces and in pores, few fine and medium roots; strongly acid (pH 5.5)

Soil name:	**Phen series: Pn**
Classification:	a) National: Low Humic Gley Soils
	b) USDA: Plinthaqualts
Described by:	Sunan Kunaporn
Date:	27 April 1976

I. INFORMATION OF THE SITE

Location:	Ban Hoi, Amphoe Wattana Nakhon, Prachinburi Province
Elevation:	30 m
Relief and slope:	nearly flat
Physiography:	shallow depression of middle terrace
Natural vegetation or land use:	paddy field
Climate:	a) climate type: Tropical Savanna
	b) Annual rainfall: 2,009 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvial
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	3 m in the dry season
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Aquults
Great groups:	Paleaquults
Subgroup:	Aeric Plinthic
Family:	Loamy-skeletal, Mixed, Isohyperthermic
Cat**ion e**xchange capacity:	Subactive
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Apg	0-14	Grayish brown (10YR5/2) loam; few fine faint dark yellowish brown (10YR4/6) mottles; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few termite holes; strongly acid (field pH 5.5); clear, smooth boundary.
Btg	14-45	Gray to grayish brown (10YR5/1-2) clay loam; many fine distinct yellowish brown (10YR5/8) and strong brown (7.5YR5/8) mottles; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; patchy thin clay coating on ped faces; few fine roots; few termite holes; strongly acid (field pH 5.5); abrupt, smooth boundary.
Btc	45-77	Light brownish gray to pale brown (10YR6/2-3) very gravelly clay loam; many fine distinct strong brown (7.5YR5/8) and common fine prominent red (2.5YR4/8) mottles (coated color around gravels); massive to weak medium subangular blocky structure; friable; sticky, plastic; patchy thin clay coating on ped faces; gravels composed of ironstones (about 70% by volume); very strongly acid (field pH 5.0); clear, smooth boundary.
BCtg1	77-120	Light brownish gray (10YR6/2) slightly gravelly clay loam; many fine distinct yellowish brown (7.5YR5/8) and prominent red (2.5YR4/8) mottles; massive to weak medium subangular blocky structure; friable, sticky, plastic; patchy thin clay coating on ped faces; gravely composed of soft red shale (2.5YR4/8-10R4/8) and ironstones; very strongly acid (field pH 4.5); clear, smooth boundary.
BCtg2	120-180	Pinkish gray (10YR7/2) slightly gravelly clay loam; other characteristics are very similar to the above horizon.

Soil name:	**Sakon series: Sk**
Classification:	a) National: Ground Water Laterite Soils
	b) USDA: Petroferic Haplustults
Described by:	Chaleao Changprai, et. al.
Date:	30 April 1971

I. INFORMATION OF THE SITE

Location:	Ban Don Noi, Amphoe Muang, Sakon Nakhon Province
Elevation:	150 m
Relief and slope:	Nearly level, slope <1 m
Physiography:	Wash surfaces
Natural vegetation or land use:	Open dipterocarp forest
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,587 mm
	c) Mean temperature: 26.1 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Alluvium over siltstone and/or shale
b. Drainage:	Poorly drained
c. Permeability:	Slow
d. Run off:	Slow
e. Ground water depth:	2 m in the dry season
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Haplustults
Subgroup:	Petroferric
Family:	Loamy-skeletal over fragmental, Mixed, Isohyperthermic
Cation exchange capacity:	Subactive
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-10	Very dark brown (10YR2/2) very gravelly loam; friable, slightly sticky, slightly plastic; many medium and coarse interstitial pores; many fine, common medium and few coarse roots; coarse fractions consists of about 80% ironstone gravels; slightly acid (field pH 6.5); clear, smooth boundary.
Bt	10-33	Dark brown to brown (7.5YR4/4) very gravelly clay loam, friable, sticky, plastic; moderately thick clay coating around the gravels and ped faces; many medium and coarse interstitial pores; common fine and few medium roots; coarse fraction consists of about 80% ironstone gravels; strongly acid (field pH 5.5); clear, smooth boundary.
C	33-40	Sheet of laterite with multicolored colors that are in shades of reddish brown, brownish grayish and whitish colors; very strongly acid (field pH 5.0).

Soil name:	**Satuk series : Suk**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Paleustults
Described by:	P. Hemsrichart B. Boonsompopphan
Date:	20 June 1981

I. INFORMATION OF THE SITE

Location:	Amphoe Muang, Khon Kaen Province
Elevation:	160-220 m
Relief and slope:	Gently undulating to undulating , slope 2-8 m
Physiography:	Higher part of peneplain
Natural vegetation or land use:	Mainly dipterocarp and mixed deciduous forest with parts cleared for upland crops such as kenaf, cassava etc
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,207.6 mm
	c) Mean temperature: 26.7 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Washed deposit from sandstone
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	< 1.5 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Paleustults
Subgroup:	Typic
Family:	Fine-loamy, Siliceous, Isohyperthermic
Cation exchange capacity:	Subactive (0.21)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-26	Dark brown to brown (7.5YR4/2) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; many very fine roots; some pieces of charcoal; strongly acid (field pH 5.5); clear, smooth boundary.
E	26-40	Brown (7.5YR5/4) with dark grayish brown (10YR4/2) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; common very fine roots; organic matter coating in some parts of horizon with some charcoal pieces; slightly acid (field pH 6.5); clear, smooth boundary.
Bt1	40-70	Strong brown (7.5YR5/6) sandy loam; moderate medium and coarse subangular blocky structure; firm, sticky, plastic; patchy thin clay coating on ped faces and in pores; common very fine roots; some krotovinas and few animal activities; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bt2	70-145	Strong brown (7.5YR5/8) sandy clay loam; strong medium and coarse subangular blocky structure; firm, sticky, plastic; broken thin clay coating on ped faces and in pores; few very fine roots; few pieces of charcoal; very strongly acid (field pH 4.5); gradual, smooth boundary.
Bt3	145-200	Strong brown (7.5YR5/8) with some spot of yellow (10YR7/6) sandy clay loam; strong medium and coarse subangular blocky structure; firm, sticky, plastic; broken thin clay coating on ped faces and in pores; few very fine and fine roots; very strongly acid (field pH 5.0).

Soil name:	**Satuk, coarse loamy variant series : Suk-col**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Paleustults
Described by:	Thamnoon Stith
Date:	-

I. INFORMATION OF THE SITE

Location:	Ban Khao Noi, Chon Buri Province
Elevation:	18.5 m
Relief and slope:	Undulating, 2-3 %
Physiography:	Middle terrace
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: -
	c) Mean temperature: -

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well to somewhat excessively drained
c. Permeability:	Estimated to be rapid
d. Run off:	Rapid
e. Ground water depth:	Below 1.5 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-14	Dark yellow brown (10YR 3/4); sandy loam; moderate fine subangular blocky structure; soft when dry, firm when moist, non sticky; non plastic; many fine interstitial and few fine tubular pores; common fine and medium roots; neutral reaction clear and smooth boundary; pH 7.0
A2	14-26	Dark brown (10YR 3/3); sandy loam and sandy clay loam; moderate fine subangular blocky structure; hard when dry, firm when moist, slightly sticky slightly plastic; many fine interstitial and tubular pores; few fine vesicular pores; few fine and medium roots; few medium round hard ironstone nodules; neutral reaction clear and smooth boundary; pH 7.0
B21	26-55	Strong brown (7.5YR 5/6) sandy clay loam; moderate medium subangular blocky strucky hard when dry; friable when moist, slightly sticky, slightly plastic; patchy thin clay coating on ped faces and in termite holes; many fine interstitial and few fine vesicular pores; few fine roots; few termite holes, few fine hard ironstone nodules; moderately alkaline reaction clear and smooth boundary; pH 8.0
B22tcn	$55\text{-}100^{+}$	Reddish brown (5YR 4/4) very gravelly sandy clay loam (gravel 80 %); gravel consist of fine and medium hard ironstone nodules; thin cutans on ped faces and nodules

Soil name:	**Warin series : Wn**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Oxic Paleustults
Described by:	Chaleao Changprai
Date:	21 Febuary 1969

I. INFORMATION OF THE SITE

Location:	Amphoe That Phanom, Nakhon Phanom Province
Elevation:	180-250 m
Relief and slope:	Gently undulating to undulating , slope 2-8 m
Physiography:	Upper part of peneplain
Natural vegetation or land use:	Mixed deciduous forest and dipterocarp forest. Parts are cleared for upland crops such as corn, cotton, sugar cane etc
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 2,163.3 mm
	c) Mean temperature: 25.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Washed deposit from sandstone
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	< 1.5 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Kandiustults
Subgroup:	Typic
Family:	Fine-loamy, Siliceous, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-10/14	Dark brown (7.5YR3/2) sandy loam with some patches of yellowish red (5YR4/8); massive; hard firm, nonsticky, nonplastic; few fine roots; few medium animal holes; common pieces of fine charcoal; strongly acid (field pH 5.5); clear, wavy boundary.
BA	10/14-26	Yellowish red (5YR5/6) sandy loam; massive; hard, firm, slightly sticky, slightly plastic; common fine tubular pores; few large roots; few large termite holes; very strongly acid (field pH 5.5); gradual, smooth boundary.
Bt1	26-48	Yellowish red (5YR4/8) sandy clay loam; moderate medium subangular blocky structure; hard, firm, sticky, plastic; broken thin clay coating in pores; common fine tubular pores; few fine roots; few large termite holes; very strongly acid (field pH 5.0); gradual, smooth boundary.
Bt2	48-100	Yellowish red (5YR5/8) sandy clay loam; moderate medium subangular blocky and some strong fine granular structure; hard, firm, sticky, plastic; continuous moderately thick clay coating in pores; common fine tubular and interstitial pores; very strongly acid (field pH 5.0); gradual, smooth boundary.
Bt3	100-120	Yellowish red (5YR458) sandy clay; common medium red (2.5YR4/8) and white (5YR8/2) mottles; sticky, plastic; very strongly acid (field pH 5.0); gradual, smooth boundary.
Bt4	120-150	Yellowish red (5YR5/8) sandy clay, hard, firm, sticky, plastic; very strongly acid (field pH 5.0); abrupt, smooth boundary.
BC	150-175	Reddish yellow (7.5YR6/6) sandy clay; few fine yellowish red (5YR4/8) and light gray (10YR7/2) mottles; sticky, plastic; very strongly acid (field pH 5.0); abrupt, smooth boundary.
2Cc	175-240	Yellowish brown (10YR5/8) and red (2.5YR4/8) clay with about 80% ironstones; very strongly acid (field pH 5.0).

Soil name:	**Ban Bueng series : Bbg**
Classification:	a) National: Hydromorphic Regosolic Gray Podzolic Soils
	b) USDA: Aquic Arinic Eutrochrepts
Described by:	Chaleao Changprai, et. al.
Date:	7 August 1973

I. INFORMATION OF THE SITE

Location:	Ban Bung, Amphoe Ban Bueng, Chon Buri Province
Elevation:	10-40 m
Relief and slope:	Level to nearly level, slope 2 %.
Physiography:	Granitic terrain
Natural vegetation or land use:	Sugar cane and cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1500 mm
	c) Mean temperature: 27 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Alluvial fan
b. Drainage:	Poorly to moderately well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	1.5 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Entisols
Suborder:	Psamments
Great groups:	Quartzipsamments
Subgroup:	Oxyaquic
Family:	Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	-

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-20	Grayish brown (10YR5/2) loamy medium sand; weak coarse subangular blocky structures breaking to single grain; friable, nonsticky and nonplastic; many fine interstitial pores, few fine and medium tubular pores; common fine roots; moderately alkaline (field pH 8.0); clear smooth boundary.
C1	20-42	Very pale brown (10YR7/3) loamy coarse sand; common coarse distinct brown to dark brown (10YR4/3) mottles; massive; slightly firm, nonsticky and nonplastic; many fine interstitial pores, few fine and medium tubular pores; more compact than above horizon; few fine roots; moderately alkaline (field pH 8.0); gradual smooth boundary.
C2	42-95	Very pale brown (10YR7/3) loamy coarse sand; many coarse distinct brown to dark brown (10YR4/3) mottles; very weak coarse subangular blocky structure breaking to single grains; friable, nonsticky and nonplastic; many fine and medium interstitial pores, common fine tubular pores; no roots; moderately alkaline (field pH 8.0); gradual smooth boundary.
C3	95-130	Light brown (7.5YR6/4) loamy coarse sand; many medium and coarse distinct strong brown (7.5YR5/6) mottles; very weak coarse subangular blocky structure breaking to single grains; friable, nonsticky and nonplastic; many fine and medium interstitial pores, few fine tubular pores; few hard iron nodules; no roots; moderately alkaline (field pH 8.0); gradual smooth boundary.
Cg	130-150	Pinkish gray (5-7.5YR7/2) loamy coarse sand; common medium and coarse distinct brownish yellow (10YR6/6) and few coarse distinct strong brown (7.5YR5/6) mottles; weak coarse subangular blocky structure breaking to single grains; firm, nonsticky and nonplastic; many fine and medium interstitial pores, few fine tubular pores; common slightly hard iron nodules; no roots; moderately alkaline (field pH 8.0).

Soil name:	**Hup Krapong series : Hg**
Classification:	a) National: Gray Podzolic Soils
	b) USDA: Ustoxic Dystropepts
Described by:	C. Kanjanaserm, S. Udomsri and K. Malairojsiri
Date:	11 May 1997

I. INFORMATION OF THE SITE

Location	Ban Hup Krapong, Amphoe Cha-am, Petchaburi Province
Elevation	50 m
Relief and slope	Nearly level to undulating, slope 1-2 %.
Physiography	Eroded hill
Natural Vegetation or Land Use	Corn, water melon and tomato
Climate	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,044.1 mm
	c) Mean temperature : 27.6 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Granite
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	>2 m
f. Other:	-

III. SOIL TAXONOMY

Order:	Alfisols
Suborder:	Ustalfs
Great groups:	Haplustalfs
Subgroup:	Typic
Family:	Coarse-loamy, Mixed, Isohyperthermic
Cation exchange capacity:	Active(0.46)
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-10/18	Mixed dark grayish brown (10YR4/2) and brown (10YR5/3) sandy loam; moderate fine and medium subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; many very fine and fine roots; slightly acid (field pH6.5); clear, wavy boundary.
Bt1	10/18-40	Mixed grayish brown (10YR5/2) and brown (10YR5/3) sandy loam; strong very fine, fine and medium subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; patchy thin clay coatings on ped faces and in pores; common very fine and few medium roots; some charcoals fragments; moderate alkaline (field pH 8.0); clear, smooth boundary.
Bt2	40-65	Pale brown (10YR6/3) coarse sandy loam; moderate very fine and fine subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; patchy thin clay coatings on ped faces and in pores; common very fine roots; some termite holes activity; moderate alkaline (field pH 8.0); clear, smooth boundary.
Bt3	65-88/90	Pale brown (10YR6/3) coarse sandy loam; moderate to strong very fine and fine subangular blocky structure; hard, friable, nonsticky, nonplastic; patchy thin clay coatings on ped faces and in pores; common very fine roots; common rounded, soft manganese concretion; moderate alkaline (field pH 8.0); clear, smooth boundary.
Bt4	88/90-140	Pale brown (10YR6/3) slightly gravelly coarse loamy sand; moderate fine and medium subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; moderately thick clay coatings on ped faces and in pores; few very fine roots; common rounded soft and hard ferrous and manganese concretion; medium acid (field pH 6.0); clear, smooth boundary.
Bt5	140-180+	Pale brown (10YR6/3) slightly gravelly coarse loamy sand; weak to moderate very fine and fine subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; patchy thin clay coatings on ped faces and in pores; common rounded soft and hard ferrous and manganese concretion; strongly acid (field pH 5.5).

Soil name:	**Kabin Buri series: Kb**
Classification:	a) National: Red Yellow Podzolic
	b) USDA: Typic Paleustults
Described by:	Thanya Timwat
Date:	5 May 1976

I. INFORMATION OF THE SITE

Location:	Laterite pit near Ban Nong Bo,Tambon Khu Yai Mi, Amphoe Phanom Sarakham, Chachoengsao Province
Elevation:	23 m
Relief and slope:	Flat slope 1-2 %.
Physiography:	Middle terrace
Natural vegetation or land use:	Shrub & cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,078.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well drained
c. Permeability:	Estimated to be rapid over moderate
d. Run off:	-
e. Ground water depth:	Below 115 cm
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-15	Brown to dark brown (10YR 4/4) and strong brown (7.5YR 5/6), sandy loam; moderate fine and medium subangular blocky structure; firm, slightly sticky, slightly plastic; common fine and medium roots; slightly acid (pH6.0); clear smooth boundary
B21tcn	15-36	Yellowish red (5YR 4/6), gravelly clay loam, moderate medium subangular blocky structure; firm sticky, slightly plastic; gravelly composed of unconsolidated ironstones about 35 % by volume and few subangular quartzite fragments of 1-1.5 cm, in diameter containing about 5 % by volume; patchy thin clay coatings on ped faces and in pores; common fine and medium roots; very strongly acid gradual wavy boundary pH 5.0
B22tcn	36-70	Red (2.5YR 4/6) gravelly clay loam; gravels composed of mainly ironstone 50 % by volume, loose ironstone having diameter of 0.5-1 cm structure cannot be described due to the presence of gravels, broken moderately thick clay coating on ped faces and in pores; common fine roots; very strongly acid gradual smooth boundary; pH 4.5
B23tcn	70-115	Red (2.5YR 4/6-4/8) gravelly clay, gravels composed of unconsolidated ironstone about 60 % by volume of the soil matrix, structure cannot be described due to the presence of gravels; broken moderately thick clay coating along vertical distance of profile; common fine roots, very strongly acid (pH 4.5)

Soil name:	**Kabin Buri, brown variant : Kb-br**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Typic Paleustults
Described by:	Suthin & Pratum
Date:	24 April 1977

I. INFORMATION OF THE SITE

Location:	Ban Hui Hin
Elevation:	40 m
Relief and slope:	Undulating, 3 %.
Physiography:	Terrace deposit
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: -
	c) Mean temperature: -

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Old alluvium
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	More than 3 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-14	Dark brown (7.5YR 4/4), sandy loam; weak fine and medium subangular blocky structure; firm, slightly sticky, non plastic; many fine and medium roots; clear smooth boundary; pH6.0
B1	14-25	Strong brown (7.5YR 5/6), heavy sandy loam; moderate medium and coarse subangular blocky structure sticky and plastic; patchy thin clay coatings on ped faces few fine roots; abrupt smooth boundary; pH 5.5
B21tcn	25-82	Strong brown (7.5YR 5/8), gravelly clay loam; patchy thin clay coating on ped faces and continuous thick in pores; gravels composed of ironstone having diameter of 0.5-2.5 cm containing about 30 % by volume few very fine roots; gradual smooth boundary; pH 5.5
B22tcn	82-110	Strong brown (7.5YR 5/8), very gravelly sandy clay, broken moderately thick clay coating on ped faces and continuous thick in pores; gravels composed of rounded and subrounded ironstone having diameter of 0.5-1.5 cm containing about 45 % by volume; pH 6.0

Soil name:	**Map Bon series: Mb**
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Typic Paleustults
Described by:	Sumrung
Date:	-

I. INFORMATION OF THE SITE

Location:	Tambon Mab Kha, Amphoe Ban Kai, Rayong Province
Elevation:	-
Relief and slope:	Undulating
Physiography:	Erosion surface and coalescing fan/alluvial fan
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 3,046.7 mm
	c) Mean temperature: 26.4 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Granite
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	>2 m throughout the year
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-20	Brown to yellow brown (10YR 5/3-4), sandy clay loam; moderate medium to coarse subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; common medium and fine interstitial pores and fine roots; clear and smooth boundary; pH 6.5
B21	20-50	Strong brown (7.5YR 5/6), medium sandy clay loam; weak fine subangular blocky structure; very friable, slightly sticky, slightly plastic; thin continuous cutan in pores; common medium and many fine interstitial pores; few very fine roots; few termite holes; gradual and smooth boundary; pH 6.0
B22t	50-86	Reddish yellow (7.5YR 6/6), slightly gravelly sandy clay; weak fine subangular blocky structure; very friable, slightly sticky and slightly plastic; thin patchy clay coatings on ped faces and slightly thick cutan in pores; many fine interstitial pores; few very fine roots; gradual and smooth boundary; pH 5.0
B23t	86-110	Reddish yellow (7.5YR 6/6), gravelly clay and common medium yellowish red (5YR 6/8); weak fine subangular blocky structure; very friable, slightly sticky and slightly plastic; slightly thick patchy clay coatings on ped faces and thick continuous in pores; pH 6.0

Soil name:	Map Bon, clayey variant : Mb-c
Classification:	a) National: Red Yellow Podzolic Soils
	b) USDA: Typic Paleustults
Described by:	Chavalit Karnjanasurm
Date:	6 June 1974

I. INFORMATION OF THE SITE

Location:	Amphoe Sanam Chai Khet, Chachoengsao Province
Elevation:	66 m
Relief and slope:	Undulating 5 %
Physiography:	Erosion surface
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Colluvium & residuum derived from granite
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Rapid
e. Ground water depth:	>2 m
f. Other::	-

III. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-15	Dark grayish brown (10YR 4/2) and brown (10YR 5/3), sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; many fine and very fine interstitial pores; many fine roots; clear and smooth boundary; pH 7.0
B1	15-32	Light brown to reddish yellow (7.5YR 6/4-4/6), sandy clay loam; moderate fine and medium subangular blocky structure; very friable, slightly sticky and slightly plastic; many fine interstitial pores and few fine tubular pores; few fine roots; with termite burrows, gradual and smooth boundary; pH 7.0
B21	32-42	Reddish yellow (5YR 6/6) gravelly clay loam; weak fine and medium subangular blocky structure; friable, slightly sticky and slightly plastic; many fine interstitial and common medium tubular pores; few fine roots; gradual and smooth boundary; pH 5.0
B22t	42-79	Yellowish red (5YR 5/8) gravelly clay loam; few fine brown to yellowish brown (10YR 5/3-4) mottles and few patchy of pinkish gray (7.5YR 7/2); moderate medium and coarse subangular blocky structure; friable, slightly sticky and slightly plastic; thin continuous coating in pores and thin patchy on ped faces; many fine interstitial and few medium tubular, few fine roots; gradual and smooth boundary; pH 5.0
B23t	79-120^{+}	Yellowish red (5YR 5/8) gravelly clay common fine pinkish gray and pink mottles; moderate medium and coarse subangular blocky structure; friable, sticky and plastic; moderately thick continuous clay coating in pores and thin patchy on ped faces; many fine interstitial and common medium tubular, few fine roots; pH 5.0

Soil name:	**Sattahip series : Sh**
Classification:	a) National : Regosols
	b) USDA : Quartzipsamments
Described by:	Viboon & Suthin
Date:	22 April 1977

I. INFORMATION OF THE SITE

Location:	Ban Khao Hin Son, Tambon Hin Son, Amphoe Phanom Sarakham, Chachoengsao Province
Elevation:	50 m
Relief and slope:	Undulating, slope 3 %.
Physiography:	Eroded hill
Natural vegetation or land use:	Cassava
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,378.6 mm
	c) Mean temperature: 27.9 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Granite
b. Drainage:	Excessively drained
c. Permeability:	Rapid
d. Run off:	Slow
e. Ground water depth:	1.25 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Entisols
Suborder:	Psamments
Great groups:	Quartzipsamments
Subgroup:	Typic
Family:	Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	-

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
Ap	0-25	Grayish brown to brown (10YR5/2-3) loamy sand; weak coarse subangular blocky structure breaking to single grain; friable, nonsticky and nonplastic; many fine interstitial pores, common fine and few medium tubular pores; many fine and few medium roots; neutral (field pH 7.0); gradual smooth boundary.
C1	25-58	Light brownish gray to pale brown (10YR6/2-3) loamy sand; weak coarse subangular blocky structure breaking to single grains; friable, nonsticky and nonplastic; many fine interstitial pores and common fine tubular pores; few fine, medium and coarse roots; neutral (field pH 7.0); diffuse smooth boundary.
C2	58-120+	Pinkish gray to pink (7.5YR7/2-3) loamy sand; massive; friable, nonsticky and nonplastic; many fine interstitial pores, common fine and few tubular pores; few medium roots; slightly acid (field pH 6.5).

Soil name:	**Tha Yang series : Ty**
Classification:	a) National : Red Yellow Podzolic Soils
	b) USDA : Paleustults
Described by:	Sanan Kaowsanan
Date:	25 December 1977

I. INFORMATION OF THE SITE

Location:	Ban Thonglang, Tambon Thonglang, Amphoe Ban Rai, Uthai Thani Province
Elevation:	200 m
Relief and slope:	Undulating, slope 3-4 %.
Physiography:	Dissected erosion surface and residual hills
Natural vegetation or land use:	Mixed deciduous and dipterocarp forest and shifting cultivation
Climate:	a) Climate type: Tropical Savanna
	b) Annual rainfall: 1,119 mm
	c) Mean temperature: 28.3 ºC

II. GENERAL INFORMATION ON THE SOIL

a. Parent material:	Colluvium
b. Drainage:	Well drained
c. Permeability:	Moderate
d. Run off:	Medium
e. Ground water depth:	>5 m
f. Other::	-

III. SOIL TAXONOMY

Order:	Ultisols
Suborder:	Ustults
Great groups:	Haplustults
Subgroup:	Kanhaplic
Family:	Loamy-skeletal, Siliceous, Isohyperthermic
Cation exchange capacity:	-
Soil reaction:	-
Upper diagnostics profile:	Ochric
Lower diagnostics profile:	Argillic

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
A	0-6	Pale brown (10YR6/3) dry, dark brown to dark yellowish brown (10YR4/3-4) moist; slightly gravelly sandy clay loam; moderate medium and fine subangular blocky structure; sticky, plastic; few common animal hole; many medium roots; slightly acid (field pH 6.5); clear boundary.
Bt1	6-35	Pale brown (10YR6/3) to light yellowish brown (10YR6/4) dry, reddish brown (5YR4/4) moist; gravelly sandy clay (gravelly about 40% by volume); moderate fine and medium subangular blocky structure; sticky, plastic; clay coatings on ped faces; few coarse roots; moderately acid (field pH 6.0); wavy boundary.
Bt2	35-80	Reddish brown (5YR5/4) dry, reddish brown (5YR4/4) moist; gravelly clay (gravelly about 50% by volume); moderate coarse subangular blocky structure; sticky, plastic; broken thin clay coatings on ped faces; few fine roots; strongly acid (field pH 5.5); gradual, wavy boundary.
Bt3	80-100	Reddish yellow (5YR6/6) dry, yellowish red (5YR4/6) moist; many coarse gravelly clay (gravelly about 50% by volume); moderate medium subangular blocky structure; sticky, plastic; clay coatings on ped faces; few fine angular quartz; very few and fine roots; very strongly acid (field pH 5.0).

CURRICULUM VITAE

NAME : Mr. Piyawat Diloksumpun

BIRTH DATE : February 5, 1969

BIRTH PLACE : Samutprakarn, Thailand

EDUCATION :

YEAR	**INSTITUTE**	**DEGREE/DIPLOMA**
1991	Kasetsart Univ.	B.Sc.(Forestry)-Forest Engineering
1996	Kasetsart Univ.	M.Sc.(Forestry)-Forest Management

POSISION/TITLE Lecturer

WORK PLACE Faculty of Forestry, Kasetsart University

SCHOLARSHIP/AWARDS Thai Government Scholarship 2004-2006