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TITLE: Genetic Diversity and Provenance Variations on Growth and Some Morphological Traits of Siamese Senna (*Senna siamea* (Lam.) Irwin et Barneby) in Thailand

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THESIS

GENETIC DIVERSITY AND PROVENANCE VARIATIONS ON GROWTH AND SOME MORPHOLOGICAL TRAITS OF SIAMESE SENNA (*Senna siamea* (LAM.) IRWIN ET BARNEBY) IN THAILAND

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Chakrit Na Takuthung 2012: Genetic Diversity and Provenance Variations on Growth and Some Morphological Traits of Siamese Senna (*Senna siamea* (Lam.) Irwin et Barneby) in Thailand. Doctor of Philosophy (Forestry), Major Field: Forestry, Faculty of Forestry. Thesis Advisor: Assistant Professor Damrong Pipatwattanakul, D.Sc. 143 pages.

Genetic diversity and provenance variations of Siamese Senna in the provenance trials were studied at Lad Krating Plantation, Chachoengsao province. The objectives were to (1) evaluate the provenance variation in desired traits including growth performances, biomass production, coppicing ability, and wood specific gravity; (2) determine the effect of management practices by fertilizer application and cutting levels for coppicing; (3) assess the genetic diversity and genetic distance. (4) clarify and understand the effect of genetic influence on phenotype. Inter simple sequence repeat (ISSR) markers were used to analyze the genetic diversity of 9 provenances of Siamese Senna in provenance trials.

Results showed the variation among provenances in all studied characteristics. The average seed width, length, thickness, and 1000-seed weight were .75 mm, 7.56 mm, 0.78 mm, and 25 g, respectively. The average survival percentage, diameter at ground level, total height, relative growth rate of diameter at ground level, relative growth rate of total height, total aboveground biomass, and wood specific gravity at 36 months old were 81.22%, 4.46 cm, 458.86 cm, 0.06 cm/cm/month, 0.07 cm/cm/month, 5.59 ton/hectare, and 056, respectively. The average coppice number, diameter at base level and total height at 6 months old were 5.88 coppices, 2 cm and 190.94 cm, respectively. The variation of fertilizer types on growth were statistically insignificant but chemical fertilizer showed the higher growth performances than the others. The coppicing ability at ground level show better coppicing ability than at 1.30 m.

ISSR analysis using 9 primers was carried out on 180 different samples. At the species level, 53 polymorphic loci were detected. The percentage of polymorphic bands (PPB) was 90.57%, Genetic diversity (H_e) was 0.262, and Shannon's information index (I) was 0.4033. Genetic differentiation (G_{st}) detected by Nei's genetic diversity analysis suggested 28% occurred among provenances. The average number of individuals exchanged between populations per generation (N_m) was 1.2503. By using ISSR markers results to assist the selection in provenance trials, the provenance from Potaram, Ratchaburi (seedlot 2002); Muang, Kanchanaburi; Muaklek, Saraburi; Takbai, Narathiwat and Chaibadal, Lopburi were recommended for planting in Chachoengsao and Eastern provinces without the problems of narrow genetic base in the future.

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Chakrit Na Takuathung

April, 2012

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GENETIC DIVERSITY AND PROVENANCE VARIATIONS ON GROWTH AND SOME MORPHOLOGICAL TRAITS OF SIAMESE SENNA (*Senna siamea* (LAM.) IRWIN ET BARNEBY) IN THAILAND

INTRODUCTION

Senna siamea (Lam.) Irwin & Barneby (family Fabaceae), Siamese Senna, is a very widespread medicinal and food plant cultivated in Southeast Asia and Sub-Saharan Africa. This species is native to South and Southeast Asia from India, Sri Lanka, Bangladesh, Myanmar, Thailand, and Malaysia down to Indonesia (Hassain, 1999; Rocas, 2003). The absolute distribution of Siamese Senna is difficult to identify since it has been cultivated worldwide and it has ability to grow in many site conditions even in saline soil (Yuvaniyama and Dissataporn, 2003). Different parts of Siamese Senna are used for various medicinal purposes (Ahn *et al.*, 1978; Sanon *et al.*, 2003; Kaur *et al.*, 2006; Mbatchi *et al.*, 2006; Morita *et al.*, 2007). The fresh young leaves and flowers are usually using as vegetables to make the Khilek curry and can cure a mild laxative and sleeping aid (Padumanonda and Gritsanapan, 2006). The wood is dense and excellent for fuel with the calorific value of 4,500 to 4,600 Kcal/kg although it produces some smoke when burning (Forestry/Fuelwood Research and Development Project, 1994; Hassain, 1999). The heartwood is decorative and durable. It is also used in agroforestry system in many countries (Mccaffery, 1996; Vanlauwe *et al.*, 2002; Luhende *et al.*, 2006). In India, using as hyper-accumulator plant for bioremediation of fly ash dump has also been reported (Jambhulkar and Juwarkar, 2009).

Nowadays, the fuel shortage is a major problem for many countries. The fossil fuel sources are limited to a few places so the price is expensive and tend to increase all the time. The uses of fossil fuel also cause a global warming phenomenon which affected the climate e.g. more frequent on flooding event. The attempt at finding alternate sources particularly the tree biomass to be used instead of fossil fuel has been conducted worldwide. The finding is not only to substitute the fuel type but it also to solve the forest destruction problem. The people in rural area rely on the uses of fuelwood and its source is from natural forest. So the criteria for wood species should also include supporting the rural life of as well.

Siamese Senna is one of the potential species for these requirements. It is an indigenous multipurpose tree species having wide range distribution, fast growing, and ability to coppice. In Thailand, there is a limited knowledge about provenance and genetic variability of important indigenous species, Siamese Senna in particular. Since environmental conditions vary extensively within the natural range of the species, it is reasonable to expect genetic differentiation among Siamese Senna populations in a number of traits. The casual observations on variations in vegetative growth and crown shape of the species in its natural habitat are indicators for the existence of genetic variation. Substantial genetic variation among natural populations for a variety of quantitative traits has been documented for economically useful tropical plantation species such as *A. mangium, A. auriculiformis, Casuarina equisetifolia, C. junghuhniana, E. urophylla, Pinus caribea* and *P. merkusii* (Pipatwattanakul, 1989; Lawskul, 1991; Swatdipakdi, 1992; Rattanachol, 1997; Chunchaowarit, 2000; Maelim, 2000; Sengloung, 2002; Wattanasuksakul, 2002; Na Takuathung, 2005; Maid, 2006; Popromsree, 2006). Conservation and sustainable use of genetic resources is dependent upon the knowledge of the extent and pattern of intra-specific variation. Therefore, variability studies are the prerequisite for genetic improvement of any tree species. Seed source testing of native species is desirable to screen the available variation for higher productivity and future breeding works. Selection of the best provenance of desired species for a given site or region is necessary for achieving maximum productivity under plantation condition.

OBJECTIVES

The general aim of the current study was to improve the production of Siamese Senna in Thailand by tree improvement program and management practices (Figure 1). Theoretically, tree improvement program increased the value of desired traits by selecting, breeding and testing. The desired traits such as growth performance were referred to phenotype which was the result of combination between genetic constitution and effect of environment. The variation due to the environmental effect was usually higher in natural stands than in plantation. In order to avoid the environmental effect, provenance trials were selected for this study. The specific objectives were described, as follows:

1. To evaluate the provenance variation in desired traits including growth performances, biomass production, coppicing ability, and wood specific gravity of Siamese Senna from 9 provenances.

2. To determine the effect of management practices by fertilizer application on growth performances, and biomass production as well as cutting levels for coppicing.

3. To assess the genetic diversity and genetic distance of Siamese Senna from 9 provenances planting in the provenance trials.

4. To clarify and understand the effect of genetic influence on phenotype of Siamese Senna from 9 provenances under the plantation condition.

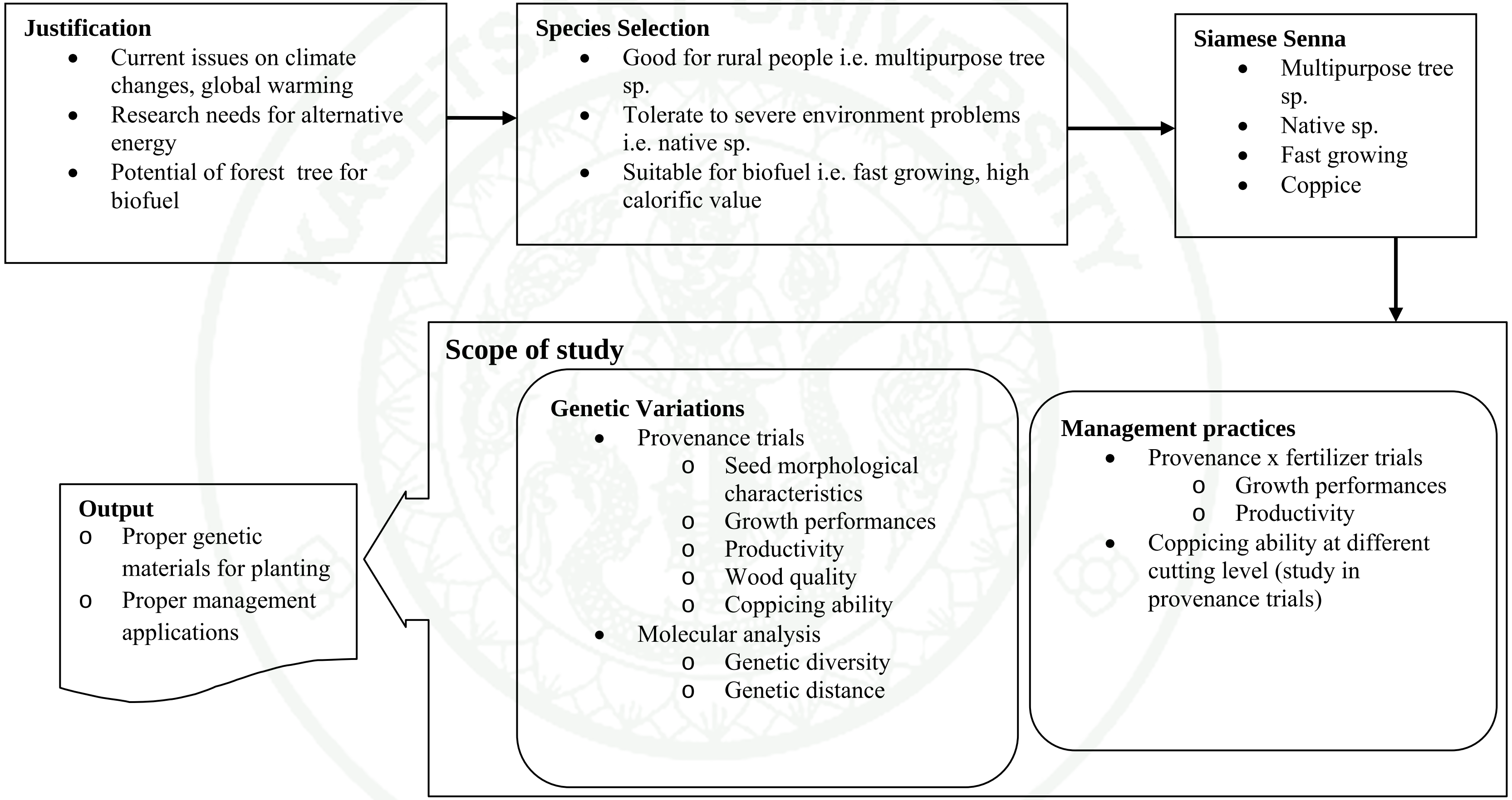

Figure 1 Conceptual framework of "Genetic Diversity and Provenance Variations on Growth and Some Morphological Traits of Siamese Senna (*Senna siamea* (Lam.) Irwin et Barneby) in Thailand".

LITERATURE REVIEWS

1. *Senna siamea* (Lam.) Irwin et Barneby

1.1 Natural distribution

Cassia siamea Lam. is an old scientific name that commonly used but it is now becoming widely known by the officially recognized name as *Senna siamea* (lam.) Irwin et Barneby (Hagrave, 2004). It is a tree species in family Fabacea (alt. Leguminosae), subfamily Caesalpinoidae and has synonym to *C. floribunda* Vahl., *S. sumatrana* Roxb. and *C. arayatensis* Naves. (Hassain, 1999; Jøker, 2000). Common names applied to the species include Bombay blackwood, Kassod tree, Siamese senna, Thailand shower, Yellow cassia, pheasantwood, Casse de Siam, Thai cassia, Bois perdrix, Flamboyán Amarillo and Khi lek (Parrota and Francis, 1990; Hassain, 1999; Jøker, 2000; USDA, 2002; Rocas, 2003; PIER, 2005a).

As shown in Figure 2, Siamese Senna is native to South and Southeast Asia from India, Sri Lanka, Bangladesh, Myanmar, Thailand, and Malaysia down to Indonesia (Hassain, 1999; Rocas, 2003). Rocas (2003) proposed that these natural distribution forms part of the warm and wet tropical forests. The absolute distribution of this species is obscure since it has been cultivated worldwide in tropic and subtropic.

The tree occurs naturally from sea level up to 1,800 m above sea level. It can grow under wide ranges of climatic condition, but it performs particularly well in lowland with a monsoon climate. For good development, it requires soils that are deep, moist, well-drained and rich in organic matters with pH ranges from 5.5 to 7.5. Average annual precipitation is 1,137 mm with a minimum annual precipitation of 500 mm and a maximum annual precipitation of 2,800 mm (optimal about 1,000 mm), average annual temperature ranges from 20 to 31°C and dry period does not exceed 4-8 months. It tolerates well drained lateritic or limestone soils and moderately acid soils (pH 5.0). It is susceptible to cold and frost or temperatures below 10°C. Naturally, latitude range is approximately limited from 25ºN to 5ºS (PIER, 2005b).

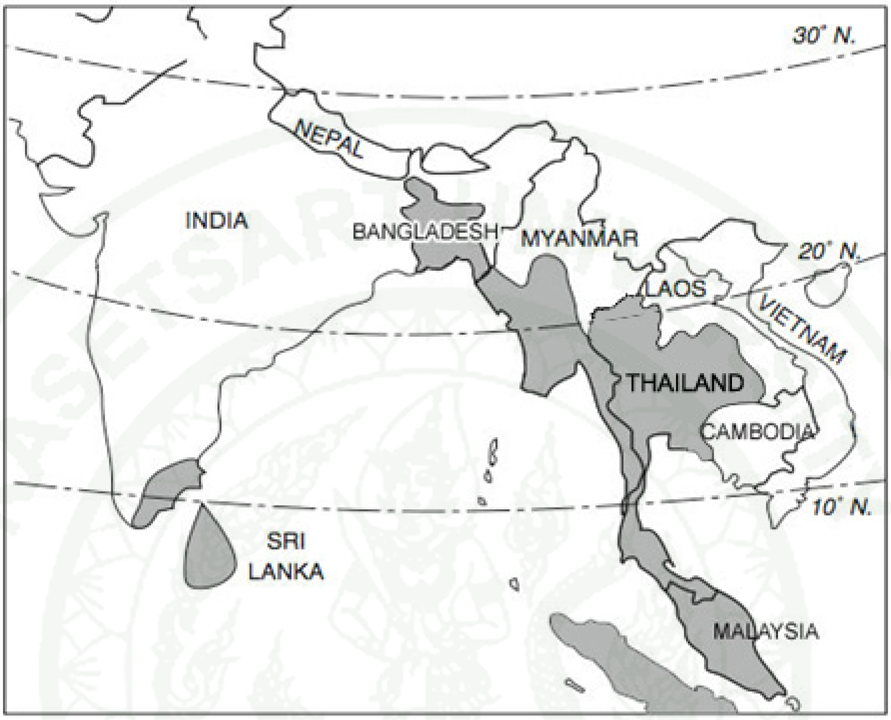

Figure 2 Natural distribution of Siamese Senna. (Modified from Parrotta and Francis, 1990)

1.2 Silvicultural characteristics

Siamese Senna is a medium size evergreen tree that is fast growing and short-lived, 10 to 12 m tall. Under optimal conditions, it can reach 30 m high and 30 cm diameter at breast height (DBH) however it rarely exceeds 20 m heigh and 50 cm DBH. Based on Private Forest Plantation Section (2001) data, Siamese Senna at 1.5 years old in 5 field trials around Thailand have the height ranging between 1.1 and 3.6 m and DBH ranging between 2.6 and 2.9 cm. The tree has a short trunk and multibranched crown which is dense and rounded at first, later becoming irregular and with dense foliage. The bark is grey and smooth when young, later with slightly longitudinal fissures. The leaves are pinnately compound with alternate arrangement, 23 to 33 cm long and made up 5 to 14 pairs of lanceolate, oblong or ovate-elliptic leaflets, 3 to 7 cm long and 12 to 20 mm wide.

Naturally, Siamese Senna flowers blooms precociusly and abundantly from June to January. Flowers and fruits can be observed in the same trees. Outside natural distribution, flowering and fruiting period occur at different times of the year, depending upon the environment (Rocas, 2003). The flowers have yellow petals and are arranged in racemes or panicles. Siamese Senna begins to fruit at 5 years old (Rocas, 2003) however at 2-3 years old is also possible (Jøker, 2000). The fruits are hanging, linear, plano-compressed legumes, 5 to 30 cm long, 12 to 20 mm wide, bicarinate, coriaceous or subwoody and dark brown and dehiscent when ripe. Each fruit contains approximately 25 seeds. The seeds range in shape from circular to obovate. In some cases are vaguely elliptic and laterally flattened. Seed size ranges from 6.5 to 9 mm long, 5.5 to 6.0 mm wide and 0.8 to 1.0 mm thick. The seedcoat is dark brown, smooth, shiny and cartaceous and 3.3 to 4.5 mm long by 0.9 to 1.2 mm wide, with a closed, oblong-elliptic pleurogram on each of its lateral surfaces (Rocas, 2003). The wood is hard, with specific gravity of 0.6 to 0.8. The sapwood is whitish, and the heartwood is dark brown to nearly black, with stripes of dark and light (Hassain, 1999).

1.3 Utilizations

Different parts of Siamese Senna are used for various medicinal purposes. Stem bark is used as a mild, pleasant and safe purgative. A decoction of bark is given in diabetes, while a paste is used as a dressing for ringworm and chilblains. The roots are used as antipyretic and leaves for constipation, hypertension and insomnia (Ahn *et al.*, 1978). The fresh young leaves and flowers are usually using as vegetables to make the Khi Lek curry and can cure a mild laxative and sleeping aid (Padumanonda and Gritsanapan, 2006). The wood is dense and excellent for fuel, although it produces some smoke when burning (Forestry/Fuelwood Research and Development Project, 1994). This species enables people in Zashe village, Kenya to collect the fuelwood nearby the house instead of walking long distances in search of fuelwood for the household and fish smoking (Jane Goodal Institute, 2005). The heartwood is decorative and durable. The calorific value is 4,500 - 4,600 Kcal/kg (Hassain, 1999).

Siamese Senna is considerable raised an international interest. In Republic of Benin, it is valued as a multipurpose tree species and farmers coppice it at 6-month intervals and sell the wood which is an important source of cash income (Mccaffery, 1996). It is also used in agroforestry system, alley cropping in Togo (Vanlauwe *et al.*, 2002) and a rotational woodlot in Tanzania (Luhende *et al.*, 2006). The latter involves growing trees with crops up to 2-3 years until trees start competing with crops. Siamese Senna showed the good survival rate in the rehabilitation of saline soil program in Northeastern Thailand (Yuvaniyama and Dissataporn, 2003). This species was introduced to Xishuangbanna village, China, for several hundred years ago as firewood source and are still using in the present (Computer Network Information Center of Chinese Academy of Sciences, n.d.). In Dai village, farmers grow Siamese Senna as the border trees around their homestead (S. Bhumibhamon, Personal Communication, March 12, 2009). Its leaves were once marketed in Thailand as an herbal drug for sleeping aid, also available in capsule form. Unfortunately, it caused a hepatotoxicity in the patients who used this kind of drug in 2000 (Chivapat *et al.*, 2001). Consequently, it was withdrawn from the market in 2003 (Padumanonda and Gritsanapan, 2006). However, the utilization as medicine is still continued with variable doses. The alcoholic extract of the flower was found to contain a large amount of polyphenols. It has potent antioxidant activity against free radicals, prevent oxidative damage to major biomolecules and afford significant protection against oxidative damage in the liver (Kaur *et al.*, 2006). In Burkina Faso and Congo, the leaves are widely used as traditional medicine, particularly for the treatment of periodic fever and malaria (Sanon *et al.*, 2003; Mbatchi *et al.*, 2006). The Cassiarin A, extracted from the leaves showed a potent antiplasmodial activity causing malaria, the leading infectious disease in many tropical and some temperate regions (Morita *et al.*, 2007). In India, it was found to accumulate heavy metals at higher concentrations compared to other species. The experimental study revealed that Siamese Senna could be used as a hyper-accumulator plant for bioremediation of fly ash dump (Jambhulkar and Juwarkar, 2009).

2. Provenance trials

The terms provenance, geographic source or geographic race are similar and can be used interchangeably. Provenance is usually defined as the original geographic area from which seed or other propagules were obtained (Zobel and Talbert, 1984). In general, the adaptability of an individual provenance will be less than that of the entire species, and major differences between provenances have been demonstrated in many species. Species with wide geographic ranges tend to show greater provenance variation than the species with limited distributions. *Eucalyptus camaldulensis,* for example, is the most widely distributed of eucalypts. Numerous overseas trials have shown that northern, tropical provenances survive and grow best in tropical summer rainfall climates, while the temperate provenances perform best in the Mediterranean, winter rainfall climates of temperate latitudes (Harwood, 2000). Siamese Senna also has wide geographic ranges. It has been cultivated worldwide but no any available information of provenance trials of this specie has previously reported.

The main practical objective of provenance trials is to determine, as quickly and as economically as possible, those provenances whose seed will produce best adapted and productive forests in a given region (Pinyopusarerk, 1987). Selection of the most productivity seed source (provenance) is very worthwhile. Most economic traits, such as vigor, exhibit about 60% of variation within and about 40% between origins(Mead, 2005). The international seedlots trials for *Eucalyptus camaldulensis* by FAO on 32 sites in 18 countries showed that growth gains of several hundred percent can be achieved by selection of the best provenance for the prevailing conditions (Libby, 2002). It illustrated the importance of provenance choice. The result also showed the significant difference between first harvesting (single stem) and second harvesting (coppice)(Sims *et al.*, 2001). Numerous studies in provenance variation reported that significant difference were found in many traits such as growth performances, morphological and anatomical characteristics, and wood quality (Pipatwattanakul, 1989; Lawskul, 1991; Swatdipakdi, 1992; Rattanachol, 1997; Chunchaowarit, 2000; Maelim, 2000; Sengloung, 2002; Wattanasuksakul, 2002; Na Takuathung, 2005; Maid, 2006; Popromsree, 2006; Krisanapant, 2007).

3. Inter-simple sequence repeat (ISSR) markers

ISSR markers are derived from polymerase chain reaction (PCR) with single primer. Primers are based on dinucleotide or trinucleotide repeat motifs. A primer sequence is generally at least 14 nucleotides long. The markers were introduced in 1994 for studies of cultivated plants and have been widely used for studies of hybridization and hybrid speciation, population and conservation genetics, and systematic investigations in natural populations. It is also being used in population study of fungi and animals (Wolfe, 2005). The advantage of ISSR approach is it does not require prior knowledge of the DNA sequence examined (Danilova *et al.*, 2003). ISSR is cost efficient, overcomes biohazards of radio activity and requires lesser amount of DNA (Zietkiewicz *et al.*, 1994). In addition, the ISSR approach does not need highly purified DNA and experience technique (Hao *et al.*, 2006). In comparison to the other three widely-used PCR-based markers including RAPDs (Williams *et al.*, 1990), SSRs or microsatellites (Tautz, 1989), and AFLPs (Vos *et al.*, 1995) as concluded by Bornet and Branchard (2001), each marker technique has its own advantages and disadvantages. RAPD markers are very quick and easy to develop (because of the arbitrary sequence of the primers) but lack reproducibility. AFLP has medium reproducibility but is labor intensive and has high operational and development costs. Microsatellites are specific and highly polymorphous but they require knowledge of the genomic sequence to design specific primers and, thus, are limited primarily to economically important species. One significant limitation of ISSRs is their dominant nature (Culley, 2009). It is difficult to calculate allele frequencies that are used to generate many common genetic statistics (e.g. number of alleles per locus, number of allele per polymorphic locus, proportion of observed heterozygotes, proportion of expected heterozygotes).

Hui-Yu *et al.* (2005) studied in *Pinus sylvestris* provenances variation by ISSR markers and found that the differentiation of the percentage of polymorphic bands among different provenance ranged from 27% to 54%. Shanon’s Information index at species level was 0.1581 and Nei’s gene diversity was 0.2393. Coefficient of gene differentiation was 0.3965. Hao *et al.* (2006) used ISSR markers to analyze the genetic diversity and genetic structure of 8 natural populations of *Cupressus chengiana* and found that at species level, the percentage of polymorphic bands (PPB) was 99%. Genetic diversity (H_e) was 0.0.3120, Shanon's Information index (I) was 0.4740. At the population level, PPB = 48%, H_e = 0.1631, and I = 0.2452. Genetic differentiation (G_{st}) detected by Nei's genetic diversity analysis suggested 48% occurred among populations.

4. Coppicing ability

Coppicing is a response of tree to a sudden death caused by cutting or damage resulting from disease, wind breakage, serious physiological disorder, fire, or other injury (Smith *et al.*, 1997). The coppices arise either from dormant buds situated on the side of the stumpat or near ground level or from adventitious buds arising from the cambial layer round the periphery of the cut surface (Matthews, 1992). The development of coppice from stump is influenced by a number of factors, as follows:

a) Meristems: position, abundance and activity of the remaining meristems on the stump (Sennerby-Forsse and Zsuffa, 1995).

b) Season of cutting: tree cut during the dormant period coppice much more vigorously than those cut during late spring and summer. This is because the reserves of carbohydrates in the roots are maximum during the winter (Kramer and Kozlowski, 1960; Matthews, 1992; Smith *et al.*, 1997).

c) Size of stump: stump of larger sizes do not coppice strongly and hence tree felling is usually done at an age not more than 40 years (Matthews, 1992). The opposite result was reported in the study of subtropical evergreen broad-leaved forest by Wu *et al.* (2008). Stump with the larger diameter at breast height (DBH) tended to have a higher mean number of coppices per stump, higher DBH, and higher tree height than the smaller stumps.

d) Height of stump: *Eucalyptus camaldulensis* at 6 and 12 months old showed the differences in number, diameter at the base level, and total height of coppices among 4 different cutting levels (Klumphabutr, 1994).

The normal coppicing method is usually managed by cutting close to the ground (Matthews, 1992) but in some case, the top of trees are removed at point above the reach of browsing animal, this form of management is pollarding (Smith *et al.*, 1997). It is however the common practice in South Asia. The bole at 2 m height will grow further and can be used as wood for house panels.

MATERIALS AND METHODS

Materials

1. Diameter tape
2. Measuring rods
3. Vernier caliper
4. Weight balance
5. Plastic and paper bags
6. Computer
7. Oven
8. Chain saw
9. Saw
10. Digging tools
11. Centrifuge machine (Sigma 2K15, USA)
12. Waterbath incubator (Taiyo, Japan)
13. DNA amplifier (Thermocycler) (Biometa T-Gradient, Germany)
14. Agarose gel electrophoresis

Methods

1. Experimental site

1.1 Field trials

The experiment was conducted at Lad Krating Plantation of Forest Industry Organization covers total area of 20,287.5 rai (3,246 ha) with 10 km long and 5 km width. The study site was located in Amphur Sanam Chaikhet, Chacherngsao province (13°14´N, 101°06´E) as shown in Figure 3. The altitude is 45 m above sea level. The average of annual temperature, rainfall, and relative humidity (RH) are 28°C, 1,220 mm, and 88% respectively. The dry period ranges between

November to February, and the maximum peak rainfall is in September, as illustrated in the climatic diagram of Lad Krating Plantation, in Figure 4.

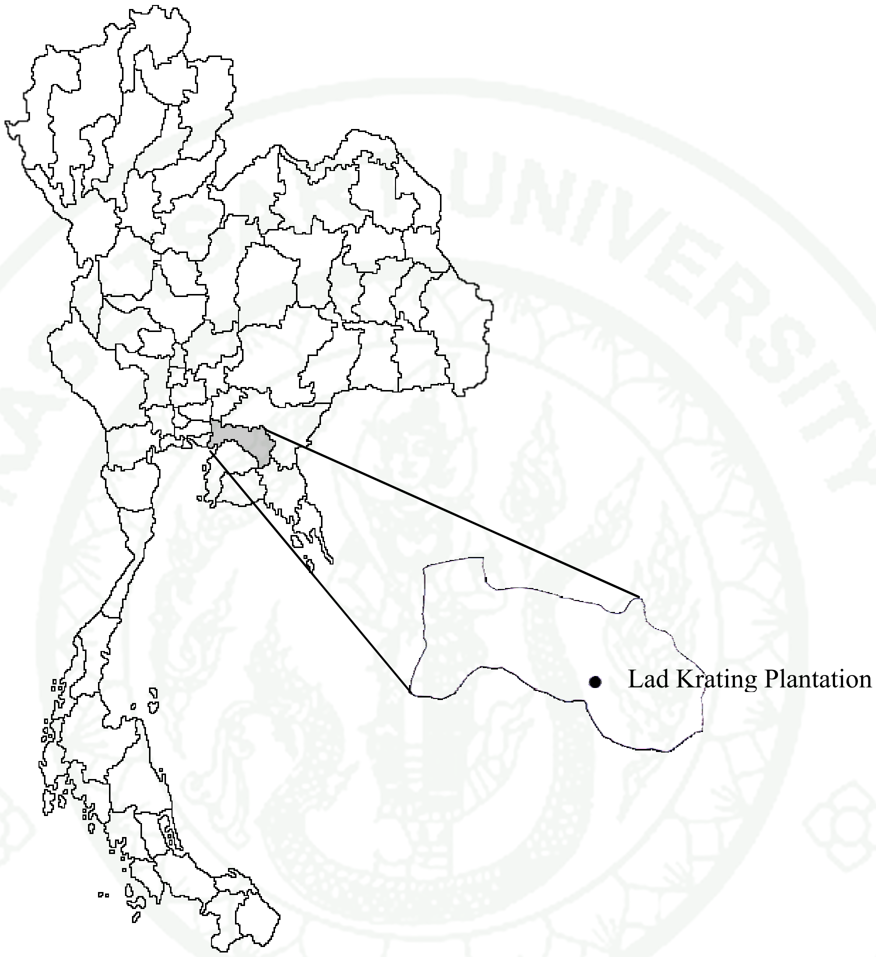

Figure 3 The experimental site at Lad Krating Plantation, Amphur Sanam Chaikhet, Chacherngsao province.

1.2 Laboratory

For the DNA study, all processes were taken at Forest Genetics Laboratory, Forest Genetic and Biotechnology Division, Department of National Parks, Wildlife and Plant Conservation.

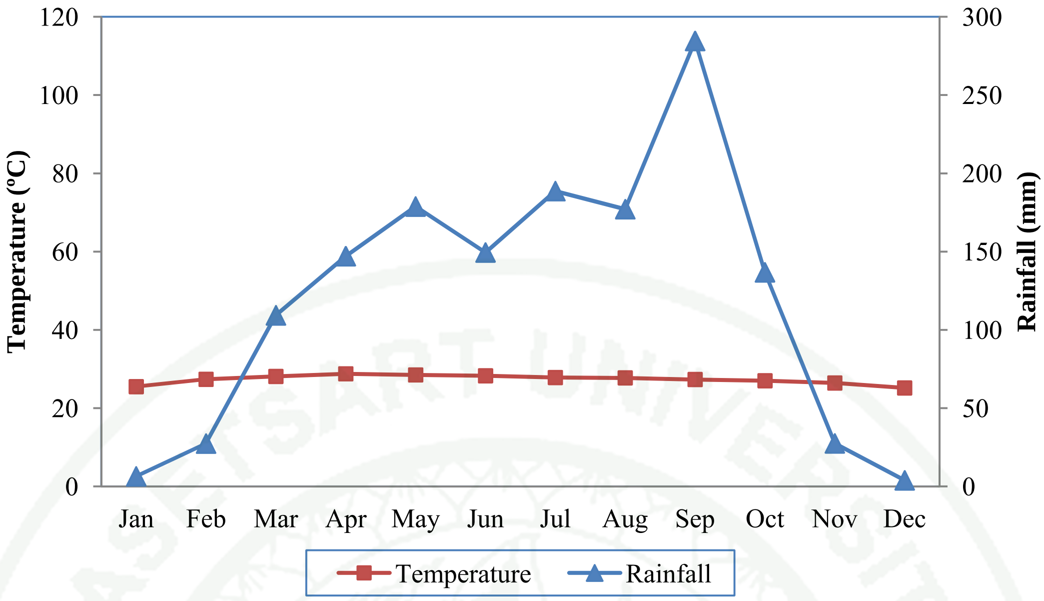

Figure 4 Climatic diagram of Lad Krating Plantation, Chachoengsao, Thailand for the periods 2002-2011. (Thai Meteorological Department)

2. Genetic Variations

2.1 Provenance trials

2.1.1 Seed morphological characteristics

The seeds of Siamese Senna used in this study were supplied by Forest Tree Seed Research and Management Section, Silviculture Research Division, Royal Forest Department (RFD). Provenances were selected based on seed sources of RFD and geographical regions of Thailand. The original sets of seed also included the provenances from Northeastern region but the germination gave insufficient number of seedlings. Therefore, provenances from Northeast were omitted in this study. The details are shown in Table 1.

Table 1 Details of Siamese Senna provenances in present study

Provenance Codes	Provinces	Districts	Regions	Altitude (m)	Rainfall (mm)[1/]	Temperature (°C)[1/]	Soil series[2/]
1	Lampang	Ngao	North	400	1,137	26.9	62, 15
2	Tak	Muang	North	350	1,114	27.9	62, 46B
3	Lop Buri	Chaibadal	Central	160	1,159	28.5	62, 47B
4	Narathiwat	Takbai	South	5	2,626	27.2	16, 58
5	Saraburi	Muaklek	Central	270	1,191	28.5	62, 52B/28B
6	Kanchanaburi	Muang	West	40	1,120	28.5	62, 33/38
7	Ratchaburi	Potaram (seedlot 2000)	Central	9	1,086	27.8	4, 6/18
8	Ratchaburi	Potaram (seedlot 2002)	Central	9	1,086	27.8	4, 6/18
9	Songkhla	Muang	South	8	2,303	28.1	39B, 43B

Source: [1/] Thai Meteorological Department

[2/] Land Development Department

2.1.1.1 Seed measurement

In order to determine the variability in seed morphological characters, seed length, seed width, seed thickness and 1000-seed weight were measured. From each provenance, a total of 400 seed were randomly selected (4 replicates of 100 seeds) and used for measuring each morphological character. Seed length, seed width and seed thickness were measured on individual seeds using a micro caliper while seed weight was determined for each replicate (100 seeds) using sensitive balance and multiply with 10 for 1000-seed weight.

2.1.1.2 Statistical analysis

The data were subjected to analysis of variance (ANOVA). Means that exhibited significant differences ($p<0.05$) were compared using the Least Square Difference (LSD) test. The variance components were calculated according to the expected mean square equation of the experimental design. In case of negative variance component is detected, restricted maximum-likelihood method was employed for variance estimation (Montgomery, 2001). To compare the magnitude of variation due to provenance and environment, provenance coefficient of variation (PCV) and environmental coefficient of variation (ECV) were computed for seed characteristics using the method described by Loha *et al.* (2006). To determine to what extent the provenance variations contributed to the total variations, broad sense heritability (H^2) was calculated as a ratio of expected mean square of the provenance variance (σ^2_{pro}) to the to the total (phenotypic) variance ($\sigma^2_{pro} + \sigma^2_{e}$) (Loha *et al.*, 2006).

2.1.2 Trials establishment

Randomized Complete Block Design (RCBD) was selected for the provenance trials establishment. Seedlings were planted on 4 blocks, each divided into 9 plots corresponding to the 9 studied provenances. Each plot was comprised of 36 trees. The density of plantation was 100 trees per rai (625 trees per hectare) obtained by using 4 x 4 m spacing (Figure 5).

2.1.3 Growth and survival percentages

The height and diameter at ground level (DGL) were measured at 1, 2, 3, 4, 5, 6, 12, 24 and 36 months after planting. All trees were measured except the border trees of each plot. Normally, diameter at breast height (1.30 m from ground) is measured but in the early stage which tree height is less than 1.30 m, DGL is used instead. Survival percentage was calculated at all stages of development. Relative growth rate (RGR) was used instead of absolute growth rate to avoid the influence of tree diffrence at the initial stage. RGR was calculated by the following formula (Hoffmann and Poorter, 2002).

$$\mathrm{RGR} = \frac{\overline{\ln(x_2)} - \overline{\ln(x_1)}}{t_2 - t_1} \tag{1}$$

Where RGR = Relative growth rate

$\overline{\ln(x_1)}$ = The means of the natural logarithm-transformed plant growth parameter (x_1) at time1 (t_1) of the sampling period

$\overline{\ln(x_2)}$ = The means of the natural logarithm-transformed plant growth parameter (x_2) at time2 (t_2) of the sampling period

2.1.4 Biomass study

The biomass study was carried out at the end of 2nd and 3rd year. All trees were classified into 5 diameter classes. Three trees in each diameter class will be selected. A total of 15 sample trees were cut at ground level. Each sample tree was divided into 3 components including stem, branch, and foliage. The stem was cut into 1 m bolt. Fresh weights of all components were determined in the field. A small sample (100 to 800 g) of stem, branch, and foliage were then collected and weighted in the field. Component samples (100 to 800 g) were oven-dried at 70°C until the weight was constant and resulting samples were used to determine moisture content and dry weight. The percentage of moisture content and total dry weight of each component were calculated as follows:

$$\%MC = \frac{SWW - SDW}{SDW} \times 100 \quad (2)$$

$$TDW = \frac{SDW}{SWW} \times TWW \quad (3)$$

Where %MC = Moisture content (percent)
SWW = Sample wet weight (g)
SDW = Sample dry weight (g)
TDW = Total dry weight (g)
TWW = Total wet weight (g)

Allometric equations were developed for stem, leaf, branch and total above ground biomass. The models were chosen based on coefficient of determination, R^2, value and appropriateness of fit when compared to actual means.

Total dry weight of each component of every tree in the field trials was estimated, using the allometric equation. Then, the average biomass of each provenance was calculated. Productivity was calculated by taking into account a plantation density of 625 trees per hectare.

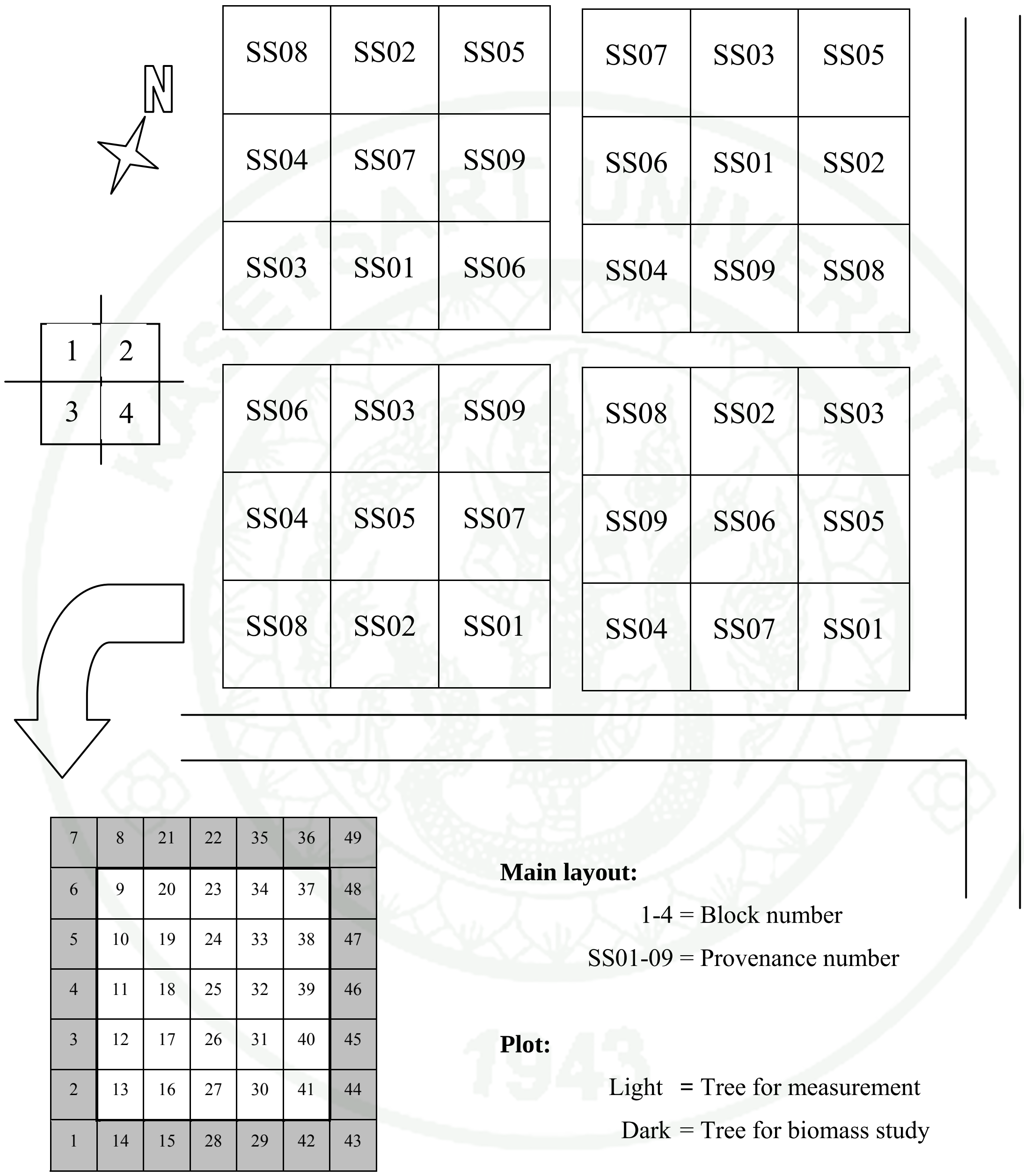

Figure 5 Layout of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao.

2.1.5 Coppicing ability

Due to the limitation of sample trees, only 7 provenances were used for coppicing study. A 2x7 factorial experiment in Completely Randomized Design (CRD) was applied. At the age of 3 years old, the 20 sample trees from each provenance were selected according to the average diameter at ground level of each provenance. Within 20 sample trees, 10 samples were cut at ground level and 10 samples were cut at 1.30 m height. Then coppice number and growth were measured during 1 to 6 month after cutting.

2.1.6 Wood specific gravity

The samples were taken from coppicing study. Ten tree samples that had been cut at ground level were cut into 5 discs at 0.5 m intervals until 2 m. Each disc was sawn to prepare 1 wood sample (1x1x1 cm^3) for wood specific gravity measurement (Figure 6).

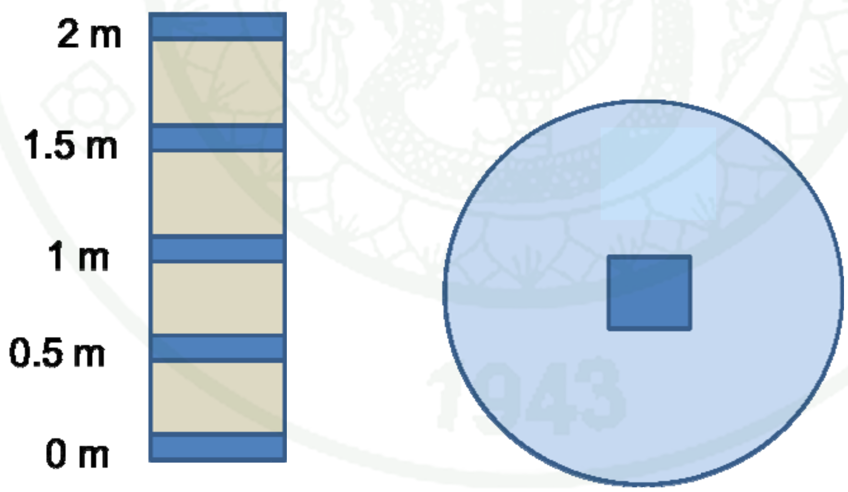

Figure 6 Diagram represents the sample preparation for wood specific gravity measurement.

After the measurement of diameter and green weight of each stem sample, the wood samples will be dried to a constant weight at 70°C. The volume of the wood samples will be determined by the water displacement method and wood specific gravity will be calculated by the following formula.

$$S_g = \frac{m_0/V}{\rho_w} \tag{4}$$

Where

S_g = Wood specific gravity
m_0 = Oven dry mass (g)
V = Volume (cm^3)
ρ_w = Density of pure water at 4°C

2.1.7 Statistical analysis

The data of survival percentages, growth performances, biomass and wood specific gravity were subjected to Analysis of Variance (ANOVA). Calculations of the variables were based on the plot means. Differences among provenances were tested with Least Significant Difference (LSD) method. In case of no statistically different among blocks for growth performances. Analysis of variance using completely randomized design was used to calculate the PCV, ECV and broad sense heritability as described in seed morphological characteristic study.

The data of coppicing ability were analyzed according to 2x7 factorial experiment in Completely Randomized Design.

2.2 Genetic variation at molecular level

2.2.1 Material collection

Materials for DNA extraction were collected based on 9 seed sources (provenance) from provenance trials (Table 1). The bud and very young leaves of 20 individuals per provenance were collected and stored in the zip lock plastic bag under the cold condition in the cool box to stabilize the cell activity. Then the samples were brought to the laboratory as soon as possible.

2.2.2 DNA extraction

Total genomic DNA was extracted from the materials in 4.1. Due to the absent of specific DNA extraction protocol for Siamese Senna, the extraction protocols were tested from various protocols including CTAB extraction (Doyle and Doyle, 1987) and Sorbitol extraction (Drabkova *et al.*, 2002). Some modifications were applied, in order to develop the suitable protocol for Siamese Senna.

2.2.2.1 CTAB extraction protocol (Doyle and Doyle, 1987)

Preheated 5-7.5 ml of CTAB isolation buffer (2% hexadecyltrimethylammonium bromide [CTAB: Sigma H-5882], 1.4 M NaCl, 0.2% 2-mercaptoethanol, 20 mM EDTA, 100 mM Tris-HCl, pH 8.0) in a 30 ml glass centrifuge tube to 60°C in a water bath. Grinded 0.5-1.0 g fresh leaf tissue in 60°C CTAB isolation buffer in a preheated mortar. Incubated sample at 60°C for 60 minutes with optional occasional gentle swirling. Extracted once with chloroform-isoamyl alcohol (24:1), mixing gently but thoroughly. Spun in centrifuge at room temperature (6,000 g) for 10 min. Removed aqueous phase with wide bore pipet, transfered to clean glass centrifuge tube, added 2/3 volumes cold isopropanol, and mixed gently to precipitate nucleic acids. Spun in centrifuge at high speed for 1-2 min. Gently poured off as much of the supernatant as possible without losing the precipitate, which will be a diffuse and very loose pellet. Added wash buffer (76% EtOH, 10 mM ammonium acetate) directly to pellet and swirled gently to resuspend nucleic acids. Spun down nucleic acids for 10 min after a minimum of 20 min of washing. Poured off supernatant carefully and allowed to air dry briefly at room temperature. Resuspended nucleic acid pellet in 1 ml TE (10 mM Tris-HCl, 1 mM EDTA, pH 7.4).

2.2.2.2 Sorbitol extraction protocol (Drabkova et al., 2002)

Grinded the plant samples with mortar and pestle, added 1.3 ml of extraction buffer (0.1 M Tris-HCL [pH 7.5], 0.005 M EDTA [pH 8.0], 0.35 M sorbitol, 10 nM 2-mercaptoethanol), transferred to 1.5 ml centrifuge tube. Incubated at room temperature for 20 minutes. Centrifuged for 5 min at 7,000 rpm at 20°C and split the supernatant. Dissolved pellet in 0.3 ml of extraction buffer and 0.3 ml of lysis buffer (0.2 M Tris-HCL [pH 7.5], 0.05 M EDTA [pH 8], 2 M NaCl, 2% CTAB), and swirled. Centrifuged for 10 min at 9,000 rpm at 20°C. Transferred the supernatant (~600 ml) into a new centrifuge tube. Added 400 ml of isopropanol, mixed well, and precipitated DNA for 1 h or longer at -20°C. Centrifuged for 10 min at 10,000 rpm at 4 °C. Added 0.7 ml of 80% EtOH and leave it overnight at -20°C. Centrifuged for 10 min at 10,000 rpm at 4°C. Took away the supernatant and dissolved pellet in 40 µl 10X TE.

2.2.3 Detection the concentration of DNA by gel electrophoresis

0.8% agarose gel (0.8% agarose gel, TBE buffer) was prepared by heating up in microwave oven, poured onto a tray, then waited for 30 min until the gel became solid, pulled out the comb and soaked gel in electrophoresis containing 1X TBE buffer. The 1 Kb DNA ladder was used as the marker at the concentration of 50 ng/µl and loaded together with 10 µl sample consisting of 5 µl sample and 1 µl loading dye. The samples were passed through 100 V electric current for 30 min. The gel was stained with ethidium bromide (0.5 µg/ml) for 10 min, rinsed with H2O for 5 min, took photo under ultraviolet light and compared each band with the marker.

2.2.4 ISSR markers

The PCR amplifications were performed in a 10 µl reaction volume containing 1 µl of 20 ng µl-1 DNA template, 1.5 µl 10X reaction buffer, 1.5 µl of 2 mM dNTPs, 1 µl of 10 ρmole µl-1 primer, 0.15 µl of 5 U Taq DNA polymerase (RBC bioscience) and 4.85 µl dH2O. Amplification was performed in a T-Gradient thermocycler (Biometa) under the following cycle profile: 5 min at 94°C, followed by

30 s at 94°C, 45 s at annealing temperature of each primer, and 2 min extension at 72 °C for 29 cycles, and 7 min at 72°C for a final extension.

2.2.5 Gel electrophoresis of ISSR products

PCR products were analyzed on 2% agarose gels in 1X TBE buffer. Gels were stained with ethidium bromide and visualized and photographed with ultraviolet light. Molecular weight was estimated using a 100 bp DNA ladder (Fermentas).

2.2.6 Data analysis

Because of the dominance of ISSR markers, it is assured that each band represented the phenotype at a single biallelic locus. Amplified bands were scored as present (1) or absent (0) for each DNA sample. The binary data matrix was imported into POPGENE (Yeh et al., 1999), assuming Hardy-Weinberg equilibrium. The following indices were used to quantify amount of genetic diversity within each provenance examined: number of polymorphic loci (N_p), the percentage of polymorphic band (PPB), Nei's gene diversity (H_e) and Shannon's information index of diversity (I). Genetic differentiation among populations was estimated by Nei's gene diversity statistics. Pairwise genetic distance between populations (Nei, 1972) was calculated to construct a UPGMA dendogram.

3. Management

3.1 Provenance and fertilizer trials

3.1.1 Trials establishment

A 4x5 factorial experiment in Randomized Complete Block Design was used for assessment of provenance and fertilizer effects and their interactions (Figure 7). There were 5 provenances of Siamese Senna and 4 types of fertilizer in 4 blocks. Each plot was composed of 9 trees. The fertilizers were applied 2 times in the first year (June and December 2006) and 1 time in each following years (June 2007 and 2008). The fertilizers used in the study are manure (200 gm/tree/year), NPK (15-15-15)(50 gm/tree/year), mixed manure and NPK (ratio 9:1, 150 gm/tree/year) and no fertilizer (control).

3.1.2 Growth and survival percentage

The height and diameter at ground level were measured at 1, 2, 3, 4, 5, 6, 12, 24 and 36 months after planting. All trees were measured except the border trees of each plot. Survival percentage were calculated at all stages of development. Relative growth rate (RGR) was used to avoid the influence of tree diffrence at the initial stage. RGR was calculated by the formula described in provenance trials (Hoffmann and Poorter, 2002).

3.1.3 Biomass study

At the end of 2^{nd} and 3^{rd} year, biomass was calculated by the allometric equation derived from study of provenance trials (2.2). Productivity was calculated by taking into account a plantation density of 625 plants per hectare.

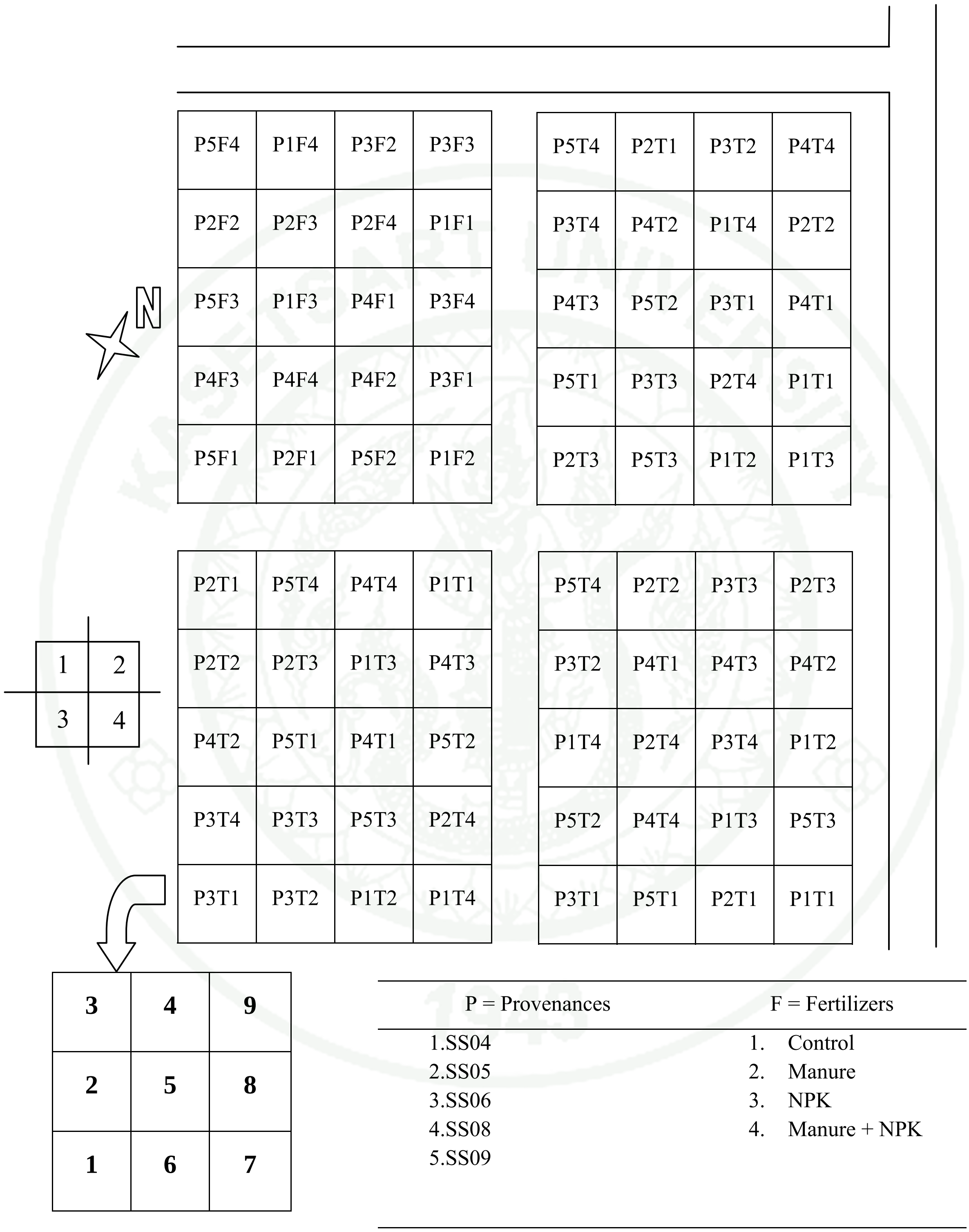

Figure 7 Layout of provenance and fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao. (1-4 are block numbers)

3.1.4 Statistical analysis

The data of survival percentages, growth performances and biomass were subjected to Analysis of Variance (ANOVA). Calculations of the variables were based on plot means. Differences among provenances were tested with Least Significant Difference (LSD) method. In case of no statistically different among blocks for growth performances. Analysis of variance using completely randomized design was used to calculate the PCV, ECV and broad sense heritability as described in seed morphological characteristic study.

3.2 Coppicing ability at different cutting level

The study was done in the same time with genetic variation study. The methodology was described as in 2.1.5.

RESULTS AND DISCUSSION

1. Genetic variations

1.1 Seed morphological characteristics

Seed is the reproductive materials contained genetic constituents from mother trees. The variation of genetic constituent expresses in variation in seed morphological characteristics and also the growth performances of these seedlings. Seed morphological characteristics including width, length, thickness and 1000-seed weight from 9 provenances are shown in Table 2. Average seed width was 5.75 mm varying from 5.50 mm (Takbai, Narathiwat provenance) to 6.09 mm (Muaklek, Saraburi provenance). The analysis of variance showed highly significant differences among provenances ($F=5.30^{**}$) (Table 3). The mean comparison by LSD separated provenances into 4 groups. The average seed length was 7.56 mm ranging from 7.22 mm (Potaram, Ratchaburi-seedlot 2000 provenance) to 8.28 mm (Muang, Songkhla provenance). The analysis of variance showed highly significant differences among provenances ($F=10.49^{**}$) (Table 3). The mean comparison by LSD separated provenances into 4 groups. The average seed thickness was 0.78 mm varied from 0.55 mm (Muang, Kanchanaburi provenance) to 0.96 mm (Muang, Songkhla provenance). The analysis of variance showed highly significant differences among provenances ($F=10.49^{**}$) (Table 3). The mean comparison by LSD separated provenances into 5 groups. The average 100-seeds weight was 2.50 g varied from 2.25 g (Potaram, Ratchaburi-seedlot 2002 provenance) to 2.76 g (Muang, Songkhla provenance). The analysis of variance showed highly significant differences among provenances ($F=24.89^{**}$) (Table 3). The mean comparison by LSD separated provenances into 6 groups.

The provenance and environmental effects on seed morphological characteristics were estimated for the current study. Provenance coefficient variance (PCV) was large for seed thickness (18.1%) compared to seed length (4%), width (3%) and 100-seed weight (5.7%) (Table 4). Environmental factors appeared to play a minor role in shaping these characteristicss, as 69-83% of the total variation was attributed to provenance variation, except seed width showing only 50%, as indicated by the broad sense heritability (Table 4).

In the present study, highly significant differences among provenances were found for all seed morphological characteristics (Table 2) and most of the total variation was a provenance effect (Table 4). Genetic control of seed morphological characteristics has been reported for several tree species including *Gliricidia sepium* (Salazar, 1986), *Cordia africana* (Loha *et al.*, 2006), *Juniperus procera* (Mamo *et al.*, 2006), *Jatropha curcas* (Rao *et al.*, 2008), and *Calophyllum inophyllum* (Hathurusingha *et al*., 2011). Fenner (1987) stated that from many experiments involving plants grown under a range of different conditions, most organs can vary markedly in size but mean seed weight usually remains almost constant. However the current study showed the significant variation within the species (Table 2). Fenner (1987) noted the sources of seed weight variation including both internal and external factors. The larger seed is normally associated with the mature trees (internal) and with the drier habitat (external). The reproductive strategy of tree also affected the seed variation, the requirements for dispersal would favor small seeds and the requirements for seedling establishment would favor large seeds (Fenner, 1987). Variation in seed morphological characteristics could also be the result of adaptation to diverse environmental conditions in their large natural distribution of this species as well. From Table 4, most of the total variation was a provenance effect and heritability was higher than 50%. The similar results were found in study on *Cordia africana* (Loha *et al.*, 2006) and *Juniperus procera* (Mamo *et al.*, 2006).

Table 2 Average seed morphological characteristics of Siamese Senna, based on 9 provenances in Thailand

Provenances	Width (mm)	Length (mm)	Thickness (mm)	1000- Seed weight (g)
1	5.68^{cd}	7.32^{cd}	0.78^{cd}	24.0^{de}
2	5.96^{ab}	7.52^{bc}	0.81^{bcd}	25.9^{b}
3	5.88^{abc}	7.62^{b}	0.75^{d}	25.9^{b}
4	5.50^{d}	7.64^{b}	0.87^{bc}	23.2^{ef}
5	6.09^{a}	7.64^{b}	0.89^{ab}	26.0^{b}
6	5.65^{cd}	7.55^{bc}	0.55^{e}	25.4^{bc}
7	5.74^{bcd}	7.22^{d}	0.76^{d}	24.7^{cd}
8	5.66^{cd}	7.31^{cd}	0.60^{e}	22.5^{f}
9	5.57^{d}	8.28^{a}	0.96^{a}	27.6^{a}
Mean	5.75	7.56	0.78	25.0
S.D.	0.18	0.31	0.13	1.6
C.V. (%)	3.19	4.11	17.11	6.35

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 3 Analysis of variance on seed morphological characteristics of Siamese Senna, based on 9 provenances in Thailand

Characteristics	Sources	DF	Variance components	Expected mean squares
Width	Provenances	8	0.03^{**}	$\sigma^2_e + 4\sigma^2_{Pro}$
	Error	27	0.03	σ^2_e
Length	Provenances	8	0.09^{**}	$\sigma^2_e + 4\sigma^2_{Pro}$
	Error	27	0.04	σ^2_e
Thickness	Provenances	8	0.02^{**}	$\sigma^2_e + 4\sigma^2_{Pro}$
	Error	27	0.004	σ^2_e
100-Seed weight	Provenances	8	0.02^{**}	$\sigma^2_e + 4\sigma^2_{Pro}$
	Error	27	0.004	σ^2_e

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

Table 4 Provenance and environment coefficient of variation and broad sense heritability for seed characteristics of Siamese Senna from 9 provenances

Characteristics	Overall mean	Coefficient of variation (%)		Heritability (%)
		Provenance	Environment	
Width (mm)	5.75	3	3	50
Length (mm)	7.56	4	2.6	69
Thickness (mm)	0.78	18.1	8.1	83
1000-Seed weight (g)	25	5.7	2.5	83

1.2 Provenance trials

1.2.1 Survival percentage

Under the plantation conditions, seedlings have to adapt to the new environment and face climatic changing during development stage toward the mature tree. Thus information on survival rate is valuable to the plantation manager. In the current study, survival percentages had been recorded at 1, 2, 3, 4, 5, 6, 12, 24 and 36 months after planting (Table 5). After 1 month, the death trees were replaced by new seedlings so the survival percentages were increased after 2 months. The survival percentage for all provenances ranged between 43-91, 69-99, 67-98, 66-97, 65-95, 64-95, 62-89, 61-89 and 61-88 percent at the age of 1, 2, 3, 4, 5, 6, 12, 24 and 36 months old, respectively. The average survival percentages of each measuring age were 63, 90.44, 89.89, 88, 87.11, 86.11, 81.89, 81.89, and 81.22 percent, respectively.

At 1 month after planting, provenance from Potaram, Ratchaburi (seedlot 2002) showed the highest survival percentage while the lowest was recorded for Muang, Songkhla provenace. The analysis of variance (Table 6) showed highly significant difference among provenance ($F=8.04^{**}$). The mean comparison by LSD divided provenances into 4 groups.

The death of one month grown seedling was partly due to the overall management of the planting site. This allowed the replanting of seedlings of the same age kept for this purpose.

After replanted, the highest and lowest survival percentages were still recorded for Potaram, Ratchaburi (seedlot 2002) provenance and Muang, Songkhla provenance, respectively, until 12 months old. At 26 and 36 months old, the highest survival percentages were Takbai, Narathiwat provenance while the lowest were Muang, Songkhla provenance (Table 5). At 2, 3, 4, 5, and 6 months after planting, analysis of variance showed the highly significant differences among provenances except at 4 months old which the difference was significant ($F=4.98^{**}$, 3.60^{**}, 3.13^{*}, 3.46^{**}, and 3.93^{**}, respectively) (Table 6). The mean comparison by LSD divided provenances into 2 groups for survival percentage at 2, 3, 4, and 5 months old while at 6 months old were divided into 3 groups. No significant differences were found at 12, 24, and 36 months old (Table 6).

Table 5 Average survival percentage of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Prove-nances	Survival percentages at various ages (months)								
	1	2	3	4	5	6	12	24	36
1	54^{cd}	92^{a}	92^{a}	92^{a}	92^{a}	91^{ab}	84	86	88
2	47^{d}	93^{a}	94^{a}	90^{a}	90^{a}	88^{ab}	83	82	81
3	75^{ab}	90^{a}	90^{a}	89^{a}	88^{a}	87^{ab}	84	83	81
4	65^{bc}	97^{a}	95^{a}	92^{a}	93^{a}	93^{a}	88	90	90
5	77^{ab}	92^{a}	93^{a}	90^{a}	90^{a}	89^{ab}	85	86	85
6	69^{bc}	88^{a}	88^{a}	84^{a}	81^{a}	79^{b}	77	78	76
7	46^{d}	94^{a}	92^{a}	92^{a}	90^{a}	89^{ab}	85	82	82
8	91^{a}	99^{a}	98^{a}	97^{a}	95^{a}	95^{a}	89	89	87
9	43^{d}	69^{b}	67^{b}	66^{b}	65^{b}	64^{c}	62	61	61
Mean	63.00	90.44	89.89	88.00	87.11	86.11	81.89	81.89	81.22
SD	15.60	8.21	8.53	8.42	8.65	8.89	7.72	8.18	8.22
C.V. (%)	24.76	9.07	9.49	9.57	9.93	10.32	9.43	9.99	10.12

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 6 Analysis of variance on survival percentage of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	1,135.56	378.52	2.78^{ns}
	Provenances	8	8,760	1,095	8.04^{**}
	Error	24	3,268.44	136.19	
2 months	Blocks	3	442.67	147.56	2.42^{ns}
	Provenances	8	2,424.89	303.11	4.98^{**}
	Error	24	1,461.33	60.89	
3 months	Blocks	3	271.56	90.52	1^{ns}
	Provenances	8	2,619.56	327.44	3.60^{**}
	Error	24	2,180.44	90.85	
4 months	Blocks	3	444.44	148.15	1.46^{ns}
	Provenances	8	2,552	319	3.13^{*}
	Error	24	2,442.56	101.81	
5 months	Blocks	3	515.56	171.85	1.77^{ns}
	Provenances	8	2,691.56	336.44	3.46^{**}
	Error	24	2,332.44	97.19	
6 months	Blocks	3	630.67	210.22	2.32^{ns}
	Provenances	8	2,843.56	355.44	3.93^{**}
	Error	24	2,173.33	90.56	
12 months	Blocks	3	737.33	245.78	1.80^{ns}
	Provenances	8	2,147.56	268.44	1.97^{ns}
	Error	24	3,274.67	136.44	
24 months	Blocks	3	844	281.33	2.09^{ns}
	Provenances	8	2,411.56	301.44	2.24^{ns}
	Error	24	3,224	134.33	
36 months	Blocks	3	623.56	207.85	1.58^{ns}
	Provenances	8	2,430.22	303.78	2.32^{ns}
	Error	24	3,148.44	131.19	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

The trend of survival percentages were continuously decreased in the first 6 months and quite constant during 12 to 36 months old. Seedlings from Muang, Songkhla provenance performed low survival percentage at all measuring ages. Even though replanting had been done after 1 month, survival rate of Muang, Songkhla provenance was still the lowest until 36 months. Based on the basic information of provenance (Table 1), Muang, Songkhla has much higher rainfall (2,303 mm) than Lad Krating plantaion (1,220 mm). This might be the reason why seedlings from Muang, Songkhla had low adaptation ability to the experimental site. However, provenance from Takbai, Narathiwat, which also has high rainfall, showed better survival percentage than provenance from Muang, Songkhla. This could be caused by the soil type differences between these 2 provenances. The survival percentage during the older stage (12-36 months old) expressed no significant differences among provenances indicating a similar adaptation of all provenances based only in term of this variable (Table 5). Bayala (2009) found the similar trend of survival percentages in *Vitellaria paradoxa* and suggested that the similarity in the older stage may be due to the fact that experimental site is within the natural occurrence area of the studied species. The lack of differences may also be due to the activity in the experimental site which the trees were protected from competition with other competitors by weeding.

The survival percentages of other species, planted at Lad Krating plantation, have been reported for many species. In *Acacia mangium,* the survival percentage was 97.75% at 7 years old (Lawskul, 1991). *Acacia auriculiformis* were found to be relatively high, varying between 98-100% at the age of 24 months old (Swatdipakdi, 1992). Jaijing (1994) reported that the survival percentage of *Tectona grandis* at 14 years old was 76.80% while the study by Thueksathit (2006) in clonal seed orchards at 18 months old was 66.44%. At the same age, *Casuarina equisetifolia* has lower survival percentage. Rattanachol (1997) recorded that, the survival percentages were 88.17, 85.76 and 63.96 percent at the age of 12, 24 and 36 months, respectively. Shiozaki (1998) revealed that the survival percentage of *Paraserianthes falcataria* was 90.9% at 18 months old. Maid (2006) reported that the survival percentage of *Eucalyptus urophylla* at 6 years old was 85.11% and decreased to 54.37% at 16 years old. Krisanapant (2007) studied on the growth of *Azadirachta indica* in clonal seed orchard and seedling seed orchard and reported that at 24 months old, the survival percentages were 70 and 90 percent, respectively. Comparison between Siamese Senna and other species grown in the same area showed that survival percentage of Siamese Senna was moderate.

1.2.2 Diameter at ground level (DGL)

DGL in provenance trials is shown in Table 7. The average DGL of all provenances at 1, 2, 3, 4, 5, 6, 12, 24, and 36 months after planting were 0.50, 0.58, 0.81, 1.06, 1.27, 1.35, 2.71, 3.21, and 4.46 cm, respectively.

At 1 month after planting, the average DGL varied between 0.44 cm (Takbai ,Narathiwat provenance) and 0.59 cm (Potaram, Ratchaburi-seedlot 2002 provenance). The results of analysis of variance (Table 8) indicated that DGL at 1 month old differed highly significantly among provenances ($F=3.43^{**}$). At 2 months after planting, DGL ranged from 0.48 cm (Potaram, Ratchaburi-seedlot 2000 provenance) to 0.74 cm (Muaklek, Saraburi provenance and Potaram, Ratchaburi-seedlot 2002 provenance). The variation among provenances (Table 8) was highly significant ($F=7.11^{**}$). At 3 months after planting, the lowest DGL was recorded for Potaram, Ratchaburi (seedlot 2000) provenance (0.64 cm) while the highest DGL was recorded Potaram, Ratchaburi (seedlot 2002) provenance (1.02 cm). The variation among provenances (Table 8) was significant ($F=3.30^{**}$). At 4 month after planting, DGL varied between 0.84 cm (Potaram, Ratchaburi-seedlot 2000 provenance) and 1.29 cm (Potaram, Ratchaburi-seedlot 2002). The results of analysis of variance (Table 8) indicated that DGL at 4 month old differed significantly among provenances ($F=2.50^{*}$). At 5 months after planting, DGL ranged from 0.98 cm (Potaram, Ratchaburi-seedlot 2000 provenance) to 1.69 cm (Muaklek, Saraburi provenance). The variation among provenances (Table 8) was not significant ($F=2.25^{ns}$). At 6 months after planting, the lowest DGL was recorded for Potaram, Ratchaburi (seedlot 2000) provenance (1.04 cm) while the highest DGL was recorded Potaram, Ratchaburi (seedlot 2002) provenance (1.74 cm). The variation among provenances (Table 8) was significant ($F=2.61^{*}$).

Table 7 Average diameter at ground level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Diameter at ground level (cm) at various ages (months)								
	1	2	3	4	5	6	12	24	36
1	0.45^{b}	0.56^{b}	0.79^{b}	1.05^{abc}	1.30	1.33^{abcd}	2.43^{bc}	2.77^{c}	3.76^{e}
2	0.51^{ab}	0.49^{b}	0.68^{b}	0.86^{c}	1.03	1.15^{cd}	2.47^{bc}	3.12^{bc}	4.56^{abcd}
3	0.48^{b}	0.55^{b}	0.78^{b}	1.02^{bc}	1.18	1.25^{bcd}	2.52^{bc}	3.13^{bc}	4.45^{bcd}
4	0.44^{b}	0.53^{b}	0.77^{b}	1.04^{abc}	1.31	1.31^{bcd}	2.59^{bc}	3.06^{bc}	4.26^{de}
5	0.58^{a}	0.74^{a}	1.01^{a}	1.35^{a}	1.69	1.67^{ab}	3.32^{a}	3.65^{a}	4.83^{abc}
6	0.47^{b}	0.58^{b}	0.83^{ab}	1.11^{abc}	1.35	1.48^{abc}	2.96^{ab}	3.44^{ab}	4.85^{ab}
7	0.48^{b}	0.48^{b}	0.64^{b}	0.84^{c}	0.98	1.04^{d}	2.23^{c}	2.90^{c}	4.01^{de}
8	0.59^{a}	0.74^{a}	1.02^{a}	1.29^{ab}	1.54	1.74^{a}	3.49^{a}	3.80^{a}	5.10^{a}
9	0.50^{b}	0.57^{b}	0.74^{b}	0.97^{c}	1.10	1.21^{cd}	2.35^{c}	3.03^{bc}	4.28^{cde}
Mean	0.50	0.58	0.81	1.06	1.27	1.35	2.71	3.21	4.46
SE	0.05	0.09	0.12	0.16	0.22	0.22	0.42	0.33	0.41
CV (%)	10.14	15.74	15.29	15.41	17.36	16.36	15.54	10.14	9.10

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

At 12 month after planting, DGL varied between 2.23 cm (Potaram, Ratchaburi-seedlot 2000 provenance) and 3.49 cm (Potaram, Ratchaburi-seedlot 2002 provenance). The results of analysis of variance (Table 8) indicated that DGL at 1 month old differed highly significantly among provenances ($F=4.65^{**}$). At 24 months after planting, DGL ranged from 2.77 cm (Ngao, Lampang provenance) to 3.80 cm (Potaram, Ratchaburi-seedlot 2002 provenance). The variation among provenances (Table 8) was highly significant ($F=4.80^{**}$). At 36 months after planting, the lowest DGL was recorded for Ngao, Lampang provenance (3.76 cm) while the highest DGL was recorded Potaram, Ratchaburi (seedlot 2002) provenance (5.10 cm). The variation among provenances (Table 8) was highly significant ($F=4.95^{**}$). The mean comparison by LSD divided provenances into 2 groups for DGL at 1, 2, and 3 months old, 3 groups at 4, 12, and 24 months old, 4 groups at 6 months old, and 5 groups at 36 months old.

There were statistically significant differences among provenances in all studied ages except at 5 months old and no statistically significant differences among blocks in all studied ages (Table 8). Therefore, analysis of variance using completely randomized design was applied (Table 9). The provenance coefficient of variance (PCV) and environment coefficient of variance (ECV) are shown in Table 10 expressing the magnitude of variation due to provenance and environment, respectively. In the first 6 months, DGL seems to be affected by environment more than provenance. Provenance gradually influenced more on DGL at the older ages. Although provenance from Potaram, Ratchaburi (seedlot 2002) was the leader in all ages, the other ranks were not consistent. The DGL growth performance was still mainly influenced by environment (Table 10). Broad sense heritability of DGL was quite low (lower than 50%). The similar result was reported for *Cordia africana* which broad sense heritability ranged between 3-13% at 4 and 8 months (Loha *et al.*, 2006). The DGL of the other species grown in Lad Krating plantation were 15.46 cm for *A. mangium* at 24 months old (Lawskul, 1991), 9.56 cm for *A. auriculiformis* at 24 months old (Swatdipakdi, 1992), 8.11 cm for *C. equisetifolia* at 36 months old (Rattanachol, 1997), 5.82 cm for *P. falcataria* at 18 months old (Shiozaki, 1998), 3.32 cm for *T. grandis* at 18 months old (Thueksathit, 2006), and 5.27 cm for *A. indica* at

30 months old (Krisanapant, 2007). Dgl of Siamese Senna was low when compare to the other fast growing species mentioned above.

Table 8 Analysis of variance on diameter at ground level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	0.0009	0.0003	0.09^{ns}
	Provenances	8	0.09	0.01	3.43^{**}
	Error	24	0.08	0.003	
2 months	Blocks	3	0.03	0.01	1.70^{ns}
	Provenances	8	0.30	0.04	7.11^{**}
	Error	24	0.13	0.01	
3 months	Blocks	3	0.08	0.03	1.27^{ns}
	Provenances	8	0.54	0.07	3.30^{*}
	Error	24	0.49	0.02	
4 months	Blocks	3	0.06	0.02	0.44^{ns}
	Provenances	8	0.96	0.12	2.50^{*}
	Error	24	1.15	0.05	
5 months	Blocks	3	0.02	0.01	0.08^{ns}
	Provenances	8	1.76	0.22	2.25^{ns}
	Error	24	2.34	0.10	
6 months	Blocks	3	0.09	0.03	0.35^{ns}
	Provenances	8	1.76	0.22	2.61^{*}
	Error	24	2.03	0.08	
12 months	Blocks	3	0.86	0.29	1.67^{ns}
	Provenances	8	6.35	0.79	4.65^{**}
	Error	24	4.10	0.17	
24 months	Blocks	3	0.55	0.18	1.85^{ns}
	Provenances	8	3.82	0.48	4.80^{**}
	Error	24	2.39	0.10	
36 months	Blocks	3	0.27	0.09	0.60^{ns}
	Provenances	8	5.91	0.74	4.95^{**}
	Error	24	3.58	0.15	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

Table 9 Analysis of variance using completely randomized design on diameter at ground level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	Variance components	Expected mean squares
1 month	Provenances	8	0.002**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.003	σ_e^2
2 months	Provenances	8	0.008**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.006	σ_e^2
3 months	Provenances	8	0.01**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.02	σ_e^2
4 months	Provenances	8	0.02**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.04	σ_e^2
5 months	Provenances	8	0.03**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.09	σ_e^2
6 months	Provenances	8	0.04*	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.08	σ_e^2
12 months	Provenances	8	0.15**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.18	σ_e^2
24 months	Provenances	8	0.09**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.11	σ_e^2
36 months	Provenances	8	0.15**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	0.14	σ_e^2

ns Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

Table 10 Provenance and environment coefficient of variation and broad sense heritability for diameter at ground level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Characteristics	Overall mean	Coefficient of variation (%)		Heritability (%)
		Provenance	Environment	
1 month	0.50	8.94	10.95	40
2 months	0.58	15.42	13.36	57
3 months	0.81	12.35	17.50	33
4 months	1.06	13.34	18.87	33
5 months	1.27	13.64	23.62	25
6 months	1.35	14.82	20.95	33
12 months	2.71	14.29	15.66	45
24 months	3.21	10.71	11.85	45
36 months	4.46	8.68	8.39	52

1.2.3 Total height

Total heights in provenance trials during 1 to 26 months are presented in Table 11. The average total height at 1 month after planting was 34.56 cm ranging from 25.40 cm (Muang, Kanchanaburi provenance) to 51.90 cm (Potaram, Ratchaburi-seedlot 2002 provenance). As given in Table 10, there was highly significant differences in total height among provenances ($F=14.67^{**}$). After 2 months, the average total height was 38.80 cm varying between 27.23 cm (Muang, Songkhla provenance) and 56.29 cm (Potaram, Ratchaburi-seedlot 2002 provenance). The results of analysis of variance (Table 12) indicated that total height at 2 month old differed highly significantly among provenances ($F=22.42^{**}$). At 3 months after planting, the average total height was 50.44 cm ranging from 36.01 cm (Potaram, Ratchaburi-seedlot 2002 provenance) to 72.24 cm (Takbai, Narathiwat provenance). The variation among provenances (Table 12) was highly significant ($F=8.57^{**}$). The average total height at 4 months after planting was 65.69 cm ranging from 48.34 cm (Muang, Songkhla provenance) to 91.10 cm (Muaklek, Saraburi provenance). As given in Table 12, there was highly significant differences in total height among provenances ($F=5.68^{**}$). After 5 months, the average total height was 79.49 cm varying between 56.70 cm (Muang, Songkhla provenance) and 106.23 cm (Muaklek, Saraburi provenance). The results of analysis of variance (Table 12) indicated that total height at 5 month old differed highly significantly among provenances ($F=3.72^{**}$). At 6 months after planting, the average total height was 82.07 cm ranging from 57.39 cm (Muang, Songkhla provenance) to 114.28 cm (Muaklek, Saraburi provenance). The variation among provenances (Table 12) was highly significant ($F=5.35^{**}$).

The average total height at 12 months after planting was 155.02 cm ranging from 113.23 cm (Muang, Songkhla provenance) to 205.80 cm (Muaklek, Saraburi provenance). As given in Table 11, there was highly significant differences in total height among provenances ($F=7.64^{**}$). After 24 months, the average total height was 317.76 cm varying between 225.10 cm (Ngao, Lampang provenance) and 377.63 cm (Muaklek, Saraburi provenance). The results of analysis of variance (Table 12) indicated that total height at 5 month old differed highly significantly among provenances ($F=10.58^{**}$). At 36 months after planting, the average total height was 458.86 cm ranging from 336.61 cm (Ngao, Lampang provenance) to 521.79 cm (Potaram, Ratchaburi-seedlot 2002 provenance). The variation among provenances (Table 12) was highly significant ($F=11.87^{**}$). The mean comparisons by LSD separated the provenances into 3 groups at 1, 2, 3, and 5 months old, 4 groups at 4, 12, and 24 months old as well as 5 groups at 6 and 36 months old.

Similar to DGL result, provenance from Potaram, Ratchaburi (seedlot 2002) performed the best height growth almost in all measuring ages. Total height showed highly significant differences among provenances at all measuring ages but no significant differences among blocks (Table 12). Analysis of variance using completely randomized design was calculated (Table 13). PCV were mostly higher than ECV (Table 14). This is different from the result of DGL. This could be due to the available of environment condition that contributed to height growth. In this case, it could be the light which was fully available in the field so the magnitude of variation in total height was mainly due to provenance. Broad sense heritability were mostly higher than 50%. This is similar to the study by Loha (2006) in *C. africana*, the broad sense heritability of height growth ranged between 57-58%. From the previous studies on other species in Lad Krating plantation, the total height of *A. mangium* at 24 months old was 626 cm (Lawskul, 1991), *A. auriculiformis* at 24 months old was 613 cm (Swatdipakdi, 1992), *C. equisetifolia* at 36 months old was 883 cm (Rattanachol, 1997), *P. falcataria* at 18 months old was 319 cm (Shiozaki, 1998), *T. grandis* at 18 months old was 226 cm (Thueksathit, 2006), and *A. indica* at 30 months old was 192 cm (Krisanapant, 2007). Height growth of Siamese Senna was quite similar to *T. grandis,* higher than *A. indica* and lower than the rest.

Table 11 Average total height of of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Total height (cm) at various ages (months)								
	1	2	3	4	5	6	12	24	36
1	26.51^{c}	31.56^{bc}	42.98^{bc}	53.71^{cd}	66.18^{bc}	66.16^{de}	114.76^{cd}	225.10^{d}	336.61^{e}
2	36.52^{b}	32.17^{bc}	40.83^{bc}	54.74^{cd}	65.06^{bc}	67.25^{cde}	142.29^{cd}	324.99^{bc}	467.84^{bc}
3	30.54^{bc}	35.55^{b}	48.37^{b}	61.26^{cd}	75.98^{bc}	78.48^{cde}	149.62^{bc}	326.00^{bc}	468.46^{bc}
4	28.04^{c}	33.68^{bc}	72.24^{a}	68.09^{bc}	83.60^{ab}	83.78^{bcd}	147.92^{bcd}	315.81^{c}	448.57^{c}
5	54.19^{a}	62.20^{a}	49.30^{b}	91.10^{a}	106.23^{a}	114.28^{a}	205.80^{a}	377.63^{a}	510.09^{ab}
6	25.40^{c}	32.91^{bc}	48.08^{b}	70.02^{bc}	85.66^{ab}	91.39^{abc}	181.02^{ab}	338.87^{abc}	512.42^{ab}
7	27.19^{c}	37.64^{b}	66.96^{a}	58.79^{cd}	71.08^{bc}	72.34^{cde}	143.89^{cd}	325.34^{bc}	474.15^{abc}
8	51.90^{a}	56.29^{a}	36.01^{c}	85.19^{ab}	104.97^{a}	107.52^{ab}	196.70^{a}	366.96^{ab}	521.79^{a}
9	30.75^{bc}	27.23^{c}	49.17^{b}	48.34^{d}	56.70^{c}	57.39^{e}	113.23^{d}	259.15^{d}	389.83^{d}
Mean	34.56	38.80	50.44	65.69	79.49	82.07	155.02	317.76	458.86
SE	10.36	11.34	11.14	13.67	16.35	18.15	31.14	45.52	57.42
CV (%)	29.98	29.22	22.09	20.81	20.57	22.11	20.08	14.33	12.51

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 12 Analysis of variance on total height of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	51.13	17.04	0.52^{ns}
	Provenances	8	3,684.35	483.04	14.67^{**}
	Error	24	790.05	32.92	
2 months	Blocks	3	32.74	10.91	0.42^{ns}
	Provenances	8	4,626.85	578.36	22.42^{**}
	Error	24	619.16	25.80	
3 months	Blocks	3	133.44	44.48	0.68^{ns}
	Provenances	8	4,467.41	558.43	8.57^{**}
	Error	24	1,562.98	65.17	
4 months	Blocks	3	260.57	86.86	0.58^{ns}
	Provenances	8	6,729.20	841.15	5.68^{**}
	Error	24	3,582.72	149.28	
5 months	Blocks	3	176.56	58.85	0.18^{ns}
	Provenances	8	9,628.65	1,203.58	3.72^{**}
	Error	24	7,759.60	323.32	
6 months	Blocks	3	280.80	93.60	0.34^{ns}
	Provenances	8	11,856.76	1,482.09	5.35^{**}
	Error	24	6,653.95	277.25	
12 months	Blocks	3	1,404.93	468.31	0.82^{ns}
	Provenances	8	34,898.42	4,362.30	7.64^{**}
	Error	24	13,706.84	571.12	
24 months	Blocks	3	1,896.90	632.30	0.72^{ns}
	Provenances	8	74,607.79	9,325.97	10.58^{**}
	Error	24	21,159.33	881.64	
36 months	Blocks	3	8,775.55	2,925.18	2.34^{ns}
	Provenances	8	118,697.31	14,837.16	11.87^{**}
	Error	24	29,999.93	1250	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

Table 13 Analysis of variance using completely randomized design on total height of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	Variance components	Expected mean squares
1 month	Provenances	8	112.97**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	31.16	σ_e^2
2 months	Provenances	8	138.56**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	24.14	σ_e^2
3 months	Provenances	8	123.89**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	62.87	σ_e^2
4 months	Provenances	8	174.70**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	142.34	σ_e^2
5 months	Provenances	8	227.41**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	293.93	σ_e^2
6 months	Provenances	8	306.31**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	256.84	σ_e^2
12 months	Provenances	8	950.65**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	559.70	σ_e^2
24 months	Provenances	8	2,118.01**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	853.93	σ_e^2
36 months	Provenances	8	3,350.26**	$\sigma_e^2 + 4\sigma_{Pro}^2$
	Error	27	1,436.13	σ_e^2

ns Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

Table 14 Provenance and environment coefficient of variation and broad sense heritability for total height of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Characteristics	Overall mean	Coefficient of variation (%)		Heritability (%)
		Provenance	Environment	
1 month	34.56	30.75	16.15	78.38
2 months	38.80	30.34	12.66	85.16
3 months	50.44	22.08	15.72	66.34
4 months	65.69	20.12	18.16	55.10
5 months	79.49	18.97	21.57	43.62
6 months	82.07	21.33	19.53	54.39
12 months	155.02	19.89	15.26	62.94
24 months	317.76	14.48	9.20	71.27
36 months	458.86	12.61	8.26	70

1.2.4 Relative growth rate of diameter at ground level (RDGL)

The relative growth rate was used in this study to avoid the effect of difference of seedling size in the initial stage. This is confirmed by the significant differences in both tree diameter at ground level and total height after 2 months (Table 8 and 12). RDGL in provenance trials are presented in Table 15. Due to the data characteristic which can be divided based on the 12 months duration, this study categorized relative growth rates into 4 growing stages including overall stage (1-36 months), early stage (1-12 months), middle stage (12-24 months), and late stage (24-36 months).

The average RDGL during 1-36 months after planting was 0.06 cm/cm/month ranging from 0.06 cm/cm/month (Ngao, Lampang; Muang, Tak; Chaibadal, Lop Buri; Muaklek, Saraburi; Potaram, Ratchaburi-seedlot 2000; Potaram, Ratchaburi-seedlot 2002; Muang, Songkhla provenances) to 0.07 cm/cm/month (Takbai, Narathiwat; Muang, Kanchanaburi provenances). As shown in Table 16, the difference in RDGL among provenances was not significant ($F=1.97^{ns}$).

At the early growing stage (1-12 months), the average RDGL was 0.15 cm/cm/month varying between 0.14 cm/cm/month (Potaram, Ratchaburi-seedlot 2000; Muang, Songkhla provenances) and 0.17 cm/cm/month (Muang, Kanchanaburi provenance). The results of analysis of variance (Table 16) indicated that RDGL at early growing stage did not differed significantly among provenances ($F=1.58^{ns}$).

At the middle growing stage (12-24 months), the average RDGL decreased to 0.02 cm/cm/month ranging from 0.01 cm/cm/month (Ngao, Lampang; Takbai, Narathiwat; Muaklek, Saraburi; Muang, Kanchanaburi; Potaram, Ratchaburi-seedlot 2002 provenances) to 0.02 cm/cm/month (Muang, Tak; Chaibadal, Lop Buri; Potaram, Ratchaburi-seedlot 2000; Muang, Songkhla provenances). The variation among provenances (Table 15) was significant ($F=2.41^{*}$).

The average RDGL at the late growing state (24-36 months) increased to 0.03 cm/cm/month ranging from 0.02 cm/cm/month (Muaklek, Saraburi; Potaram, Ratchaburi-seedlot 2002 provenances) to 0.03 cm/cm/month (Ngao, Lampang; Muang, Tak; Chaibadal, Lop Buri; Takbai, Narathiwat; Muang, Kanchanaburi; Potaram, Ratchaburi-seedlot 2000; Muang, Songkhla provenances). As given in Table 15, there was no significant differences in relative growth rate of DGL among provenances ($F=1.59^{ns}$). The mean comparisons by LSD separated the provenances at the middle growing stage into 3 groups.

RDGL was highest in the early growing stage and relatively low in the later stage (Table 15). In addition, there was no significant difference in the early growing stage (Table 16). This indicates the important of initial size of seedling. The bigger size of initial seedling tends to have the bigger size of tree. The growth rate in the middle growing stage was lower than others because of the big difference in climatic condition as the cumulative rainfall in the early growing stage (June 2006-May 2007) was 1,790.9 mm, the middle growing stage (June 2007-May 2008) was 1,175.6 mm and the late growing stage (June 2008-May 2009) was 1,865.2 mm.

Table 15 Average diameter at ground level relative growth rate of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Relative growth rate (cm/cm/month) at various stages (months)			
	Overall	1-12	12-24	24-36
1	0.06	0.15	0.01^{abc}	0.03
2	0.06	0.15	0.02^{a}	0.03
3	0.06	0.15	0.02^{ab}	0.03
4	0.07	0.16	0.01^{abc}	0.03
5	0.06	0.16	0.01^{bc}	0.02
6	0.07	0.17	0.01^{abc}	0.03
7	0.06	0.14	0.02^{a}	0.03
8	0.06	0.16	0.01^{c}	0.02
9	0.06	0.14	0.02^{a}	0.03
Mean	0.06	0.15	0.02	0.03
SE	0.002	0.011	0.006	0.003

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 16 Analysis of variance on diameter at ground level relative growth rate of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Stages	Sources	DF	SS	MS	F
Overall	Blocks	3	$1.3\text{x}10^{-5}$	$4.6\text{x}10^{-6}$	0.40^{ns}
	Provenances	8	$1.8\text{x}10^{-4}$	$2.2\text{x}10^{-5}$	1.97^{ns}
	Error	24	$2.7\text{x}10^{-4}$	$1.1\text{x}10^{-5}$	
1-12 months	Blocks	3	$9.8\text{x}10^{-4}$	$3.3\text{x}10^{-4}$	1.15^{ns}
	Provenances	8	0.004	$4.5\text{x}10^{-4}$	1.58^{ns}
	Error	24	0.007	$2.8\text{x}10^{-4}$	
12-24 months	Blocks	3	$3.8\text{x}10^{-4}$	$1.3\text{x}10^{-4}$	2.37^{ns}
	Provenances	8	0.001	$1.3\text{x}10^{-4}$	2.41^{*}
	Error	24	0.001	$5.4\text{x}10^{-5}$	
24-36 months	Blocks	3	$1.8\text{x}10^{-4}$	$5.9\text{x}10^{-5}$	3.40^{*}
	Provenances	8	$2.2\text{x}10^{-4}$	$2.7\text{x}10^{-5}$	1.59^{ns}
	Error	24	$4.1\text{x}10^{-4}$	$1.7\text{x}10^{-5}$	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.2.5 Relative growth rate of total height

Total height relative growth rates in provenance trials are presented in Table 17. The average relative growth rate of total height during 1-36 months after planting was 0.07 cm/cm/month ranging from 0.06 cm/cm/month (Muaklek, Saraburi provenance) to 0.09 cm/cm/month (Muang, Kanchanaburi provenances). As shown in Table 18, the difference in relative growth rate of total height among provenances was highly significant ($F=8.57^{**}$).

At the early growing stage (1-12 months), the average relative growth rate of total height was 0.14 cm/cm/month varying between 0.12 cm/cm/month (Muang, Tak; Muaklek, Saraburi; Potaram, Ratchaburi-seedlot 2002; Muang, Songkhla provenances) and 0.18 cm/cm/month (Muang, Kanchanaburi provenance). The results of analysis of variance (Table 18) indicated that growth rate of total height at early growing stage differed highly significantly among provenances ($F=5.34^{**}$).

At the middle growing stage (12-24 months), the average relative growth rate of total height decreased to 0.06 cm/cm/month ranging from 0.05 cm/cm/month (Muaklek, Saraburi; Muang, Kanchanaburi; Potaram, Ratchaburi-seedlot 2002 provenances) to 0.07 cm/cm/month (Muang, Tak; Chaibadal, Lop Buri; Potaram, Ratchaburi-seedlot 2000; Muang, Songkhla provenances). The variation among provenances (Table 18) was highly significant ($F=4.97^{**}$).

The average relative growth rate of total height at the late growing state (24-36 months) decreased to 0.03 cm/cm/month. All provenances had the same rate at 0.03 cm/cm/month. So there was no significant differences in relative growth rate of total height among provenances ($F=0.89^{ns}$) (Table 18). The mean comparisons by LSD separated the provenances into 5 groups at overall growing stage and 4 groups at early and middle growing stages.

The total height relative growth rates were highly significant difference in early, middle and overall growing stages. This reveals that there was a genetic control over total height relative growth rate. The overall stage showed the highest relative growth rate of total height in Muang, Kanchanaburi provenance which was different from the highest of actual height at 36 months old (Potaram, Ratchaburi – seedlot 2002). This is due to the initial size of seedling as shown in Table 12 which provenance from Potaram, Ratchaburi (seedlot 2002) was the tallest provenance. In contrast to RDGL, total height relative growth rate in the middle growing stage was higher than in the late growing stage. This character may be not influenced by cumulative rainfall as happen in RDGL but may rather be influenced by light which was highly available in the field. So the relative growth rate of total height was not controlled by the limitation of environment. The trend of total height relative growth rate was decreased with the older age corresponded to increasing of competition between growing trees.

Table 17 Average total height relative growth rate of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Relative growth rate (cm/cm/month) at various stages (months)			
	Overall	1-12	12-24	24-36
1	0.07^{cd}	0.13^{bc}	0.06^{bc}	0.03
2	0.07^{c}	0.12^{c}	0.07^{a}	0.03
3	0.08^{bc}	0.14^{bc}	0.07^{ab}	0.03
4	0.08^{abc}	0.15^{b}	0.06^{ab}	0.03
5	0.06^{e}	0.12^{c}	0.05^{c}	0.03
6	0.09^{a}	0.18^{a}	0.05^{c}	0.03
7	0.08^{ab}	0.15^{b}	0.07^{a}	0.03
8	0.07^{de}	0.12^{c}	0.05^{c}	0.03
9	0.07^{cd}	0.12^{c}	0.07^{a}	0.03
Mean	0.07	0.14	0.06	0.03
SE	0.007	0.020	0.008	0.003

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 18 Analysis of variance on total height relative growth rate of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Stages	Sources	DF	SS	MS	F
Overall	Blocks	3	$1.2x10^{-4}$	$4x10^{-5}$	1.64^{ns}
	Provenances	8	0.002	$2.1x10^{-4}$	8.57^{**}
	Error	24	$5.9x10^{-4}$	$2.5x10^{-5}$	
1-12 months	Blocks	3	0.001	$3.6x10^{-4}$	1.16^{ns}
	Provenances	8	0.01	0.002	5.34^{**}
	Error	24	0.007	$3.1x10^{-4}$	
12-24 months	Blocks	3	$3.1x10^{-4}$	$1x10^{-4}$	2.15^{ns}
	Provenances	8	0.002	$2.4\ x10^{-4}$	4.97^{**}
	Error	24	0.001	$4.8x10^{-5}$	
24-36 months	Blocks	3	$6.8x10^{-5}$	$2.3x10^{-5}$	0.57^{ns}
	Provenances	8	$2.8x10^{-4}$	$3.5x10^{-5}$	0.89^{ns}
	Error	24	$9.6x10^{-4}$	$4x10^{-5}$	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.2.6 Biomass

1.2.6.1 Allometric equations at 24 and 36 months old

The study on biomass of Siamese Senna was done at 24 and 36 months old. The allometric equations were developed separately for each age. Based on 4 size class of DGL at 24 months old, 15 sample trees were selected for allometric equation development. Allometric equation calculated from relationship between growth performances (DGL and total height) and dry weight at 24 months old were shown in Figure 8. The coefficients of determination R^2 were highest for exponential equation ($Y = a.X^b$). The best parameters (X) fitted to the equation were DGL^2H (Table 19). The allometric equations of stem, leaves, and total aboveground biomass were highly fitted (R^2 = 0.96, 0.97 and 0.96 respectively) while the lowest fitted equation was found for branches (R^2 = 0.67).

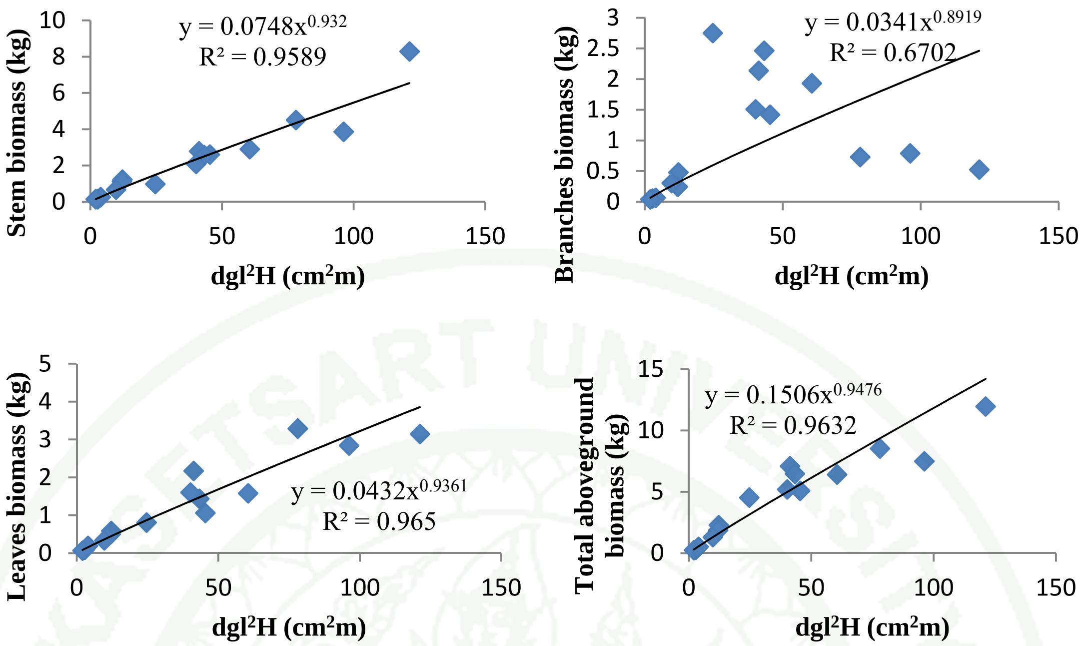

Figure 8 Allometric relationship between DGL^{2}H and biomass of provenance trials of Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006.

Table 19 The allometric equations ($Y = a.X^b$) for predicting biomass of provenance trials of Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006

Components	Equations	R^2
Stem	$Y = 0.0748(DGL^2H)^{0.932}$	0.96
Leaves	$Y = 0.0432(DGL^2H)^{0.9361}$	0.97
Branches	$Y = 0.0341(DGL^2H)^{0.8919}$	0.67
Total	$Y = 0.1506(DGL^2H)^{0.9476}$	0.96

At 36 months old, 15 sample trees were selected for allometric equation development based on 5 size class of DGL. Allometric equation calculated from relationship between tree growth performances (DGL and total height) and biomass at 36 months old were shown in Figure 9. The coefficients of determination R^2 were highest for exponential equation ($Y=a.X^b$). The best parameter (X) fitted to the equation was DGL^{2}H (Table 20). The allometric equations of stem, leaves, branches and total aboveground biomass were highly fitted (R^2 = 0.96, 0.94, 0.97 and 0.97 respectively).

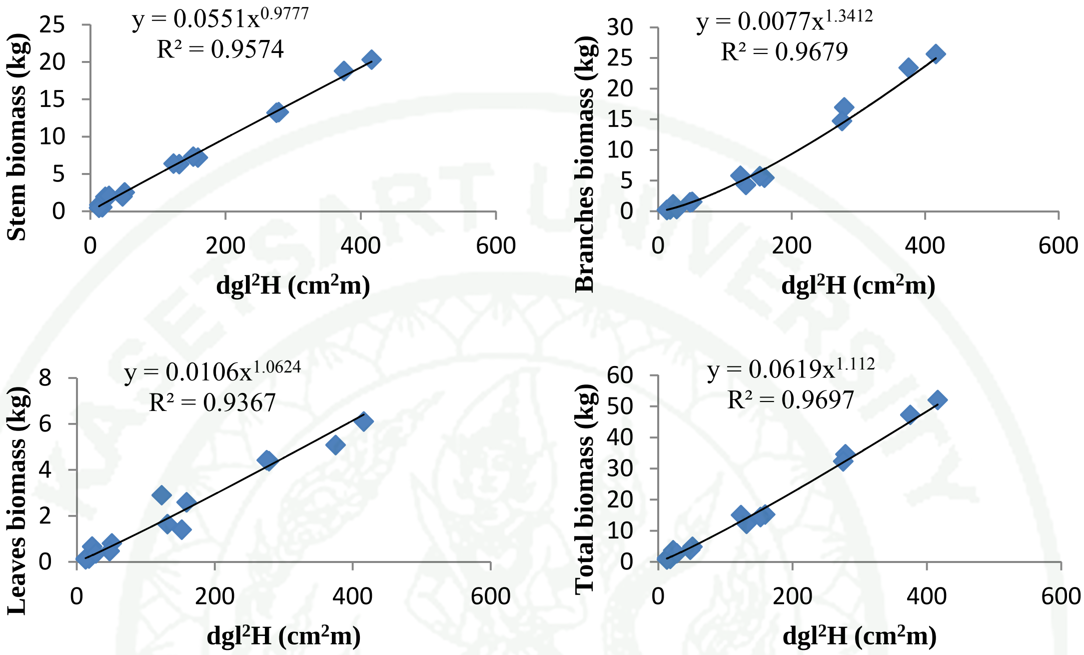

Figure 9 Allometric relationship between DGL^2H and biomass of provenance trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Table 20 The allometric equations ($Y = a.X^b$) for predicting biomass of provenance trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Parts	Equations	R^2
Stem	$Y = 0.0551(DGL^2H)^{0.9777}$	0.96
Leaves	$Y = 0.0106(DGL^2H)^{1.0624}$	0.94
Branches	$Y = 0.0077(DGL^2H)^{1.3412}$	0.97
Total	$Y = 0.0619(DGL^2H)^{1.112}$	0.97

1.2.6.2 Biomass at 24 months old

Biomass in the provenance trials at 24 months old were calculated by using the allometric equations at 24 months old (Table 16). The results are shown in Table 21. The average biomass of stem was 1.77 ton/hectare. The highest was Potaram, Ratchaburi (seedlot 2002) provenance (2.64 ton/hectare) while the lowest was Ngao, Lampang provenance (1.05 ton/hectare). The average biomass of leaves was 1.06 ton/hectare ranging from 0.63 ton/hectare (Ngao, Lampang provenance) to 1.59 ton/hectare (Potaram, Ratchaburi - seedlot 2002). The average biomass of branches was 0.83 ton/hectare ranging from 0.50 ton/hectare (Ngao, Lampang provenance) to 1.22 ton/hectare (Potaram, Ratchaburi - seedlot 2002). The average biomass of total aboveground components was 3.63 ton/hectare with the same trend of each part which the highest was Potaram, Ratchaburi (seedlot 2002) provenance (5.48 ton/hectare) and the lowest was Ngao, Lampang provenance (2.11 ton/hectare). The analysis of variance (Table 22) showed significant differences among provenances for all components ($F=8.26\text{-}8.35^{**}$). The mean comparison by LSD separated provenances into 5 groups.

Table 21 Biomass of provenance trials of provenance trials Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Biomass (ton/hectare)			
	Stem	Leaves	Branches	Total
1	1.05[e]	0.63	0.50	2.11
2	1.69[cd]	1.02	0.79	3.47
3	1.72[cd]	1.03	0.81	3.51
4	1.62[cd]	0.97	0.76	3.31
5	2.46[ab]	1.48	1.14	5.10
6	2.01[bc]	1.21	0.94	4.12
7	1.43[de]	0.86	0.68	2.92
8	2.64[a]	1.59	1.22	5.48
9	1.30[de]	0.78	0.62	2.65
Mean	1.77	1.06	0.83	3.63
SE	0.52	0.32	0.24	1.10
CV (%)	29.54	29.65	28.42	30.41

Remarks: The mean comparisons as shown in letter are similar for all components due to the same parameters, including DGL and total height at the same age, were used in all allometric equations

Table 22 Analysis of variance on biomass in provenance trials of Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006

Components	Sources	DF	SS	MS	F
Stem	Blocks	3	0.82	0.27	2.08^{ns}
	Provenances	8	8.68	1.09	8.26^{**}
	Error	24	3.15	0.13	
Leaves	Blocks	3	0.30	0.10	2.08^{ns}
	Provenances	8	3.17	0.40	8.28^{**}
	Error	24	1.15	0.5	
Branches	Blocks	3	0.17	0.06	2.07^{ns}
	Provenances	8	1.78	0.22	8.31^{**}
	Error	24	0.64	0.03	
Total	Blocks	3	3.64	1.21	2.09^{ns}
	Provenances	8	38.69	4.84	8.35^{**}
	Error	24	13.90	0.58	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.2.6.3 Biomass at 36 months old

Biomass in the provenance trials at 36 months old were calculated by using the allometric equations at 36 months old (Table 18). The results are shown in Table 23. The average biomass of stem was 3.69 ton/hectare. The highest was Potaram, Ratchaburi (seedlot 2002) provenance (5.15 ton/hectare) while the lowest was Ngao, Lampang provenance (2.14 ton/hectare). The average biomass of leaves was 0.77 ton/hectare ranging from 0.43 ton/hectare (Ngao, Lampang provenance) to 1.09 ton/hectare (Potaram, Ratchaburi - seedlot 2002). The average biomass of branches was 0.58 ton/hectare ranging from 0.29 ton/hectare (Ngao, Lampang provenance) to 0.88 ton/hectare (Potaram, Ratchaburi - seedlot 2002). The average biomass of total aboveground components was 5.59 ton/hectare with the same trend of each part which the highest was Potaram, Ratchaburi (seedlot 2002) provenance (8.06 ton/hectare) and the lowest was Ngao, Lampang provenance (3.04

ton/hectare). The analysis of variance (Table 24) showed significant differences among provenances for all components (F=5.15-5.94**). The mean comparison by LSD separated provenances into 5 groups.

Table 23 Biomass of provenance trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Biomass (ton/hectare)			
	Stem	Leaves	Branches	Total
1	2.14^{e}	0.43	0.29	3.04
2	3.98^{abcd}	0.83	0.65	6.11
3	3.82^{bcd}	0.79	0.60	5.80
4	3.30^{cde}	0.68	0.50	4.93
5	4.37^{abc}	0.91	0.70	6.67
6	4.57^{ab}	0.96	0.75	7.05
7	2.99^{de}	0.61	0.43	4.38
8	5.15^{a}	1.09	0.88	8.06
9	2.90^{de}	0.59	0.42	4.27
Mean	3.69	0.77	0.58	5.59
SE	0.94	0.21	0.19	1.57
CV (%)	25.60	27.23	32.20	28.16

Remarks: The mean comparisons as shown in letter are similar for all components due to the same parameters, including DGL and total height at the same age, were used in all allometric equations

Table 24 Analysis of variance on biomass of provenance trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Components	Sources	DF	SS	MS	F
Stem	Blocks	3	1.11	0.37	0.64^{ns}
	Provenances	8	27.76	3.47	5.94^{**}
	Error	24	14.01	0.58	
Leaves	Blocks	3	0.05	0.02	0.62^{ns}
	Provenances	8	1.35	0.17	5.80^{**}
	Error	24	0.70	0.03	
Branches	Blocks	3	0.04	0.01	0.56^{ns}
	Provenances	8	1.07	0.13	5.15^{**}
	Error	24	0.62	0.03	
Total	Blocks	3	3.10	1.03	0.61^{ns}
	Provenances	8	76.79	8.60	5.67^{**}
	Error	24	40.65	1.69	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

At 36 months old, the order of biomass from high to low in all components presented almost in the same trend as found at 24 months old (Table 25). There were some differences in rank number 2 to 5. The provenance from Potaram, Ratchaburi (seedlot 2002) grown very well in Lad Krating Plantation. This could be the result of low soil moisture content in the provenance trials. The trees were planted with 4x4 m spacing and the crown development in the first 3 years were not fully covered the area so there were a lot of open space allowing the evaporation of soil. The provenance from Potaram , Ratchaburi (seedlot 2002) had the lowest rainfall compared to other provenances (Table 1) so this provenance could adapt to the dry area better than the others.

Table 25 The biomass ranking of each component at 24 and 36 months old of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ranking	Provenances							
	Stem		Leaves		Branches		Total	
	24 m	36 m	24 m	36 m	24 m	36 m	24 m	36 m
1	8	8	8	8	8	8	8	8
2	5	6	5	6	5	6	5	6
3	6	5	6	5	6	5	6	5
4	3	2	3	2	3	2	3	2
5	2	3	2	3	2	3	2	3
6	4	4	4	4	4	4	4	4
7	7	7	7	7	7	7	7	7
8	9	9	9	9	9	9	9	9
9	1	1	1	1	1	1	1	1

1.2.6.4 Comparison between allometry equations at different ages

In order to test the methodology, whether allometry equation of different ages can be used interchangeably or not, the growth parameters at 36 months old were calculated by the allometery equations of stem at 24 and 36 months old. The results are shown in Table 26. The mean biomasses of stem computed by different equations were highly different. The comparison by t-test showed that the differences of biomasses between these 2 equations were statistically highly significant with t-value of 5.59. This result suggests that the allometric equation at 24 and 36 months old cannot be used interchangeably because the development of tree high was still high during these ages. Using the wrong equation could lead to the wrong results.

Table 26 Biomass computed by allometry equation of stem at 24 and 36 months old using growth parameters at 36 months old of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Biomass (ton/hectare)	
	Equation at 24 months old	Equation at 36 months old
1	0.31	2.14
2	0.56	3.98
3	0.54	3.82
4	0.47	3.30
5	0.61	4.37
6	0.64	4.58
7	0.43	2.99
8	0.72	5.15
9	0.41	2.90
Mean	0.52	3.69

1.2.7 Wood specific gravity

The wood specific gravity results are shown in Table 27. The average wood specific gravity of all samples was 0.56. At height level 0 m, the highest wood specific gravity was Muang, Tak provenance (0.60) while the lowest was Takbai, Narathiwat provenance (0.53). At height level 0.5 m, the highest wood specific gravity was Muang, Tak provenance and Takbai, Narathiwat provenance (0.61) while the lowest was Ngao, Lampang provenance (0.53). At height level 1 m, the highest wood specific gravity was Takbai, Narathiwat provenance (0.61) while the lowest was Ngao, Lampang provenance (0.54). At height level 1.5 m, the highest wood specific gravity was Takbai, Narathiwat provenance (0.59) while the lowest was Potaram, Ratchaburi (lot 2002) (0.52). At height level 2 m, the highest wood specific gravity were Takbai, Narathiwat provenance and Muaklek, Saraburi provenance (0.56) while the lowest was Potaram, Ratchaburi (lot 2002) provenance (0.50). The analysis of variance (Table 28) showed highly significant difference among provenances ($F=4.26^{**}$) and among height level (6.52^{**}). The mean comparison by LSD separated provenances into 3 groups. The highest wood specific gravity were Muang, Tak and Takbai, Narathiwat provenances (0.58) while the lowest were Ngao, Lampang and Potaram, Ratchaburi (seedlot 2002) provenances (0.54). The mean comparison by LSD also separated height levels into 3 groups. The highest wood specific gravity were 0 and 0.5 m level (0.57) while the lowest was 2 m level (0.53).

Table 27 Wood specific gravity of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Height levels (m)					Mean
	0	0.5	1	1.5	2	
1	0.56	0.53	0.54	0.53	0.51	0.54^{c}
2	0.60	0.61	0.57	0.57	0.53	0.58^{a}
3	0.57	0.59	0.56	0.54	0.54	0.56^{abc}
4	0.53	0.61	0.61	0.59	0.56	0.58^{a}
5	0.59	0.57	0.58	0.56	0.56	0.57^{ab}
7	0.56	0.57	0.56	0.53	0.52	0.55^{bc}
8	0.57	0.56	0.55	0.52	0.50	0.54^{c}
Mean	0.57^{a}	0.57^{a}	0.56^{ab}	0.54^{bc}	0.53^{c}	0.56
SE	0.02	0.03	0.02	0.02	0.02	0.02
CV (%)	4.19	4.93	3.96	4.36	4.49	3.13

Table 28 Analysis of variance on wood specific gravity of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Sources	DF	SS	MS	F
Levels	4	0.85	0.02	6.52^{**}
Provenances	6	0.83	0.01	4.26^{**}
Levels x provenances	24	0.06	0.003	0.82^{ns}
Error	276	0.90	0.003	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

The average wood specific gravity in the current study was 0.56. Hassain (1999) reported the higher values of specific gravity which was 0.6-0.8. This is due to the difference in age of study tree. Wood specific gravity was highest at 0 m height level and tended to decrease with the higher height level (Table 24). This pattern is similar to the variation pattern in *Acacia mangium* (Pipatwattanakul, 1989; Na Takuathung, 2005), and many conifer and hardwood species reported by Zobel and Van Buijtenen (1989). Zobel and Van Buijtenen (1989) stated that specific gravity is determined by several characteristics of wood such as cell size and wall thicknesss, the ratio of earlywood to latewood, the amount of ray cells, the size and amount of vessel elements, as well as chemical deposits within and between the cells. Cell characteristics, especially cell size and wall thickness, are closely related to the growth and development of cell. As zone of cell division, elongation, and maturation occur at apical meristem in the stem tip (Bidwell, 1979), the mature cells (big size and thick wall) decrease from base to top of the stem resulting as variation of specific gravity pattern found in this study. The variation among provenances was highly significant difference (Table 35). The similar results were found for many tree species both softwoods and hardwoods (Zobel and Jett, 1995). This indicates the influence of provenance on wood specific gravity. In the current study, the highest provenances were from Muang, Tak and Takbai, Narathiwat which were the North and the South of experimental site so the variation in wood specific gravity of this study was not related with the latitude. Zobel and Van Buijtenen (1989) stated that wood properties as related to provenance are a complex. Strong relationships are usually not found, but occasionally provenance plays an important role in determining wood properties.

1.2.8 Coppicing ability

The results of coppicing ability study were composed of 2 parts including genetic variations (among provenances) part and management (among cutting levels) part. Due to the experimental design was 2x7 factorial experiment in completely randomized design which studied 2 factors in one experiment so the results of 2 parts are shown together in this section.

1.2.8.1 Number of coppice

Number of coppice of Siamese Senna planted in provenance is shown in Table 29. At 1 month after planting, the average coppice number was 8.06. The highest coppice number was 12 (Potaram, Ratchaburi - seedlot 2002 provenance cut at 1.30 m). The lowest was 5.67 (Ngao, Lampang provenance cut at 1.30 m). The highest coppice number for provenance was 10.29 (Takbai, Narathiwat provenance) while the lowest was 6.15 (Muang, Tak provenance). Comparison between cut levels showed higher number at 1.30 m level (8.02 coppices). The analysis of variance (Table 30) showed highly significant differences among provenances ($F=2.02^{**}$) and insignificant differences among levels. The mean comparison by LSD separated provenances into 2 groups. At 2 months after planting, the average coppice number was 8.82. The highest coppice number was 13.71 (Potaram, Ratchaburi - seedlot 2002 provenance cut at 1.30 m). The lowest was 6.43 (Potaram, Ratchaburi - seedlot 2000 provenance cut at 1.30 m). The highest coppice number for provenance was 11.20 (Potaram, Ratchaburi - seedlot 2002 provenance) while the lowest was 7.29 (Ngao, Lampang provenance). Comparison between cut levels showed higher number at 0 m level (9.03 coppices). The analysis of variance (Table 30) showed no significant differences in all sources of variations. At 3 months after planting, the average coppice number was 8.36. The highest coppice number was 11.10 (Chaibadal, Lopburi provenances cut at 1.30 m). The lowest was 5.63 (Potaram, Ratchaburi - seedlot 2000 provenance cut at 1.30 m). The highest coppice number for provenance was 9.76 (Takbai, Narathiwat provenance) while the lowest was 6.88 (Ngao, Lampang provenance). Comparison between cut levels showed higher number at 0 m level (9.37 coppices). The analysis of variance (Table 30) showed no significant differences in all sources of variations. At 4 months after planting, the average coppice number was 8.74. The highest coppice number was 11.40 (Takbai, Narathiwat provenance cut at 0 m). The lowest was 6.20 (Ngao, Lampang provenance cut at 0 m). The highest coppice number for provenance was 10.41 (Takbai, Narathiwat provenance) while the lowest was 6.59 (Ngao, Lampang provenance). Comparison between cut levels showed higher number at 0 m level (8.85 coppices). The analysis of variance (Table 30) showed no significant differences in all sources of variations. At 5 months after planting, the average coppice number was 6.22. The highest coppice number was 8.57 (Muaklek, Saraburi provenances cut at 1.30 m). The lowest was 2.75 (Potaram, Ratchaburi – seedlot 2002 provenance cut at 0 m). The highest coppice number for provenance was 7.35 (Takbai, Narathiwat provenance) while the lowest was 5.19 (Ngao, Lampang provenance). Comparison between cut levels showed higher number at 1.30 m level (7.51 coppices). The analysis of variance (Table 30) showed highly significant differences between levels (16.83^{**}) and significant differences between interaction of levels - provenances (2.32^{*}). At 6 months after planting, the average coppice number was 5.88. The highest coppice number was 8.71 (Ngao, Lampang provenances cut at 1.30 m). The lowest was 3.40 (Ngao, Lampang provenance cut at 0 m). The highest coppice number for provenance was 7.06 (Takbai, Narathiwat provenance) while the lowest was 5.27 (Potaram, Ratchaburi – seedlot 2002 provenance). Comparison between cut levels showed higher number at 1.30 m level (6.56 coppices). The analysis of variance (Table 30) showed significant differences between levels (5.63^{*}) and between interaction of levels - provenances (2.61^{*}).

Number of coppice showed significant differences among provenances only at 1 month after cutting (Table 30). This is because of the available of space on the stool. At 1st month old, new coppices increased with no limitation of space but at older age it was controlled by the space of stool. Provenance from Takbai, Narathiwat showed the highest number of coppice in all measuring ages. Table 29 shows the decreasing trend of coppice number from 1 to 6 months in both cutting levels. The decreasing of coppice number was happened mostly at 0 m cutting level. Consequently, the differences among cutting levels were statistically significant at older ages (5 and 6 months old) which number of coppice at 1.30 cutting level was higher than at 0 m level. The similar results was reported in *E. camaldulensis* by (Klumphabutr, 1994). Number of coppice of *E. camaldulensis* at 6 and 12 months old were highest at 90 cm cutting level following with 60, 30, and 0 cm cutting levels, respectively. From the results of number of coppice between cutting levels, it can be suggested that in order to detect the difference, the measurement can be done from 5 months old.

Table 29 Number of coppice of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Levels (m)/	Number of coppice at various months					
provenances	1	2	3	4	5	6
0/1	7.00	6.60	7.09	6.20	3.22	3.40
0/2	5.85	9.20	9.10	9.10	4.73	4.73
0/3	8.50	10.20	11.10	10.90	7.40	7.00
0/4	10.40	11.70	10.90	11.40	6.60	6.90
0/5	7.33	6.71	6.29	8.14	4.50	4.50
0/7	8.89	9.11	8.78	10.78	6.00	6.25
0/8	8.50	9.00	8.00	8.78	2.75	4.38
1.30/1	5.67	8.29	6.40	7.14	7.71	8.71
1.30/2	6.71	7.17	7.86	7.25	8.50	6.88
1.30/3	6.40	6.70	7.00	6.60	6.10	5.60
1.30/4	10.14	8.86	8.14	9.00	8.43	7.29
1.30/5	9.43	9.29	8.43	10.29	8.57	6.86
1.30/7	7.00	6.43	5.63	6.50	6.00	4.88
1.30/8	12.00	13.71	10.86	10.00	7.88	6.29
Provenances						
1	6.43[b]	7.29	6.88	6.59	5.19	5.59
2	6.15[b]	8.44	8.59	8.28	6.32	5.63
3	7.45[ab]	8.45	9.05	8.75	6.75	6.30
4	10.29[a]	10.53	9.76	10.41	7.35	7.06
5	8.46[ab]	8.00	7.36	9.21	6.40	5.60
7	8.00[ab]	7.94	7.29	8.76	6.00	5.56
8	10.13[a]	11.20	9.25	9.31	5.31	5.27
Levels						
0	8.02	9.03	8.85	9.37	5.12[b]	5.32[b]
1.30	8.12	8.55	7.73	7.98	7.51[a]	6.56[a]
Mean	8.06	8.82	8.36	8.74	6.22	5.88

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 30 Analysis of variance on number of coppice of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Levels	1	0.44	0.44	0.02^{ns}
	Provenances	6	259.63	43.27	2.02^{**}
	Levels x provenances	6	106.87	17.81	0.83^{ns}
	Error	102	2,184.55	21.42	
2 months	Levels	1	2.48	2.48	0.12^{ns}
	Provenances	6	197.71	32.95	1.61^{ns}
	Levels x provenances	6	249.37	41.56	2.04^{ns}
	Error	101	2,061.81	20.41	
3 months	Levels	1	27.51	27.51	1.46^{ns}
	Provenances	6	122.47	20.41	1.08^{ns}
	Levels x provenances	6	173.01	28.83	1.53^{ns}
	Error	103	1,939.95	18.83	
4 months	Levels	1	43.04	43.04	2.46^{ns}
	Provenances	6	121.03	20.17	1.15^{ns}
	Levels x provenances	6	175.74	29.29	1.68^{ns}
	Error	105	1,835.95	17.49	
5 months	Levels	1	194.18	194.18	16.83^{**}
	Provenances	6	58.85	9.81	0.85^{ns}
	Levels x provenances	6	160.27	26.71	2.32^{*}
	Error	106	1,222.67	11.53	
6 months	Levels	1	51.71	51.71	5.63^{*}
	Provenances	6	33.56	5.59	0.61^{ns}
	Levels x provenances	6	143.71	23.95	2.61^{*}
	Error	105	964.15	9.18	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.2.8.2 Diameter at base level of coppice (DBL)

DBL of coppice of Siamese Senna planted in provenance trials is shown in Table 31. At 1 month after planting, the average DBL of coppice was 0.81 cm. The highest DBL of coppice was 0.91 cm (Muaklek, Saraburi provenance cut at 1.30 m). The lowest was 0.56 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 0.86 cm (Chaibadal, Lopburi and Muaklek, Saraburi provenances) while the lowest was 0.80 cm (Ngao, Lampang provenance). Comparison between cut levels showed higher DBL of coppice at 0 m level (8.02 cm). The analysis of variance (Table 32) showed no significant differences in all sources. At 2 months after planting, the average DBL of coppice was 1.05 cm. The highest DBL of coppice was 1.23 cm (Muang, Tak provenance cut at 0 m). The lowest was 0.69 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 1.13 cm (Muang, Tak provenance) while the lowest was 0.93 cm (Potaram, Ratchaburi – seedlot 2002 provenance). Comparison between cut levels showed higher DBL of coppice at 0 m level (1.14 cm). The analysis of variance (Table 32) showed highly significant differences between levels (11.95^{**}). At 3 months after planting, the average DBL of coppice was 1.09 cm. The highest DBL of coppice was 1.38 cm (Potaram, Ratchaburi – seedlot 2000 provenance cut at 0 m). The lowest was 0.73 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 1.13 cm (Muang, Tak provenance) while the lowest was 0.73 cm (Takbai, Narathiwat provenance). Comparison between cut levels showed higher DBL of coppice at 0 m level (1.22 cm). The analysis of variance (Table 32) showed highly significant differences between levels (13.26^{**}) and significant difference between provenances (2.35^{*}). The mean comparison by LSD separated provenances into 3 groups. At 4 months after planting, the average DBL of coppice was 1.17 cm. The highest DBL of coppice was 1.54 cm (Muaklek, Saraburi provenance cut at 0 m). The lowest was 0.69 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 1.39 cm (Ngao, Lampang provenance) while the lowest was 0.99 cm (Takbai, Narathiwat provenance). Comparison between cut levels showed higher DBL of coppice at 0 m level (1.30 cm). The analysis of variance (Table 32) showed highly significant differences between levels (17.17^{**}) and significant difference between provenances (2.53^{*}). The mean comparison by LSD separated provenances into 3 groups. At 5 months after planting, the average DBL of coppice was 1.80 cm. The highest DBL of coppice was 2.44 cm (Potaram, Ratchaburi – seedlot 2002 provenance cut at 0 m). The lowest was 1 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 1.99 cm (Ngao, Lampang provenance) while the lowest was 1.55 cm (Chaibadal, Lopburi and Takbai, Narathiwat provenances). Comparison between cut levels showed higher DBL of coppice at 0 m level (2.18 cm). The analysis of variance (Table 32) showed highly significant differences between levels (58.48^{**}). At 6 months after planting, the average DBL of coppice was 2 cm. The highest DBL of coppice was 2.82 cm (Potaram, Ratchaburi – seedlot 2000 provenance cut at 0 m). The lowest was 1.36 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest DBL of coppice for provenance was 2.26 cm (Muang, Tak and Poraram , Ratchaburi – seedlot 2000 provenances) while the lowest was 1.39 cm (Takbai, Narathiwat provenances). Comparison between cut levels showed higher DBL of coppice at 0 m level (2.20 cm). The analysis of variance (Table 32) showed highly significant differences between levels (7.91^{**}).

The differences of DBL of coppice among provenances were significant only at 3 and 4 months old but not significant at older ages. This is due to the limitation of stump basal area, as showed in Table 29 and Table 31, the provenances with higher number of coppice had lower size of DBL. In contrast, the differences of DBL of coppice among cutting level were statistically significant since 2 months old which DBL of coppice at 0 m was higher. This could be due to the transportation of water and nutrient from the root. The transportation system from root to coppice at 1.30 m was more difficult than to coppice at 0 m. Klumphabutr (1994) reported that in *E. camaldulensis* at 6 months old, the DBL of coppice was highest at 0 m cutting level while at 12 moths, the highest DBL of coppice was found at 30 cm cutting level. This suggested that the development of coppice can be varied when the coppice get older. The study of DBL of coppice in Siamese Senna cannot be concluded at the current study.

Table 31 Average coppice diameter at base level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Levels (m)/ provenances	Diameter of coppice (cm) at various months					
	1	2	3	4	5	6
0/1	0.74	1.00	1.19	1.41	2.22	1.98
0/2	0.86	1.23	1.28	1.40	2.35	2.53
0/3	0.85	1.18	1.07	1.15	1.77	2.03
0/4	0.77	1.19	1.14	1.21	1.93	1.42
0/5	0.81	1.22	1.31	1.54	2.36	2.62
0/7	0.85	1.15	1.38	1.21	2.30	2.82
0/8	0.86	1.02	1.08	1.23	2.44	2.20
1.30/1	0.87	1.19	1.29	1.36	1.68	1.67
1.30/2	0.79	0.95	1.03	1.06	1.47	1.90
1.30/3	0.88	0.95	0.82	1.04	1.32	1.81
1.30/4	0.56	0.69	0.73	0.69	1.00	1.36
1.30/5	0.91	1.02	1.16	1.06	1.32	1.82
1.30/7	0.81	0.89	0.90	0.90	1.21	1.71
1.30/8	0.71	0.82	0.85	0.94	1.40	2.02
Provenances						
1	0.80	1.08	1.22^{ab}	1.39^{a}	1.99	1.85
2	0.84	1.13	1.18^{abc}	1.25^{abc}	1.98	2.26
3	0.86	1.07	0.95^{c}	1.10^{bc}	1.55	1.92
4	0.68	0.98	0.97^{c}	0.99^{c}	1.55	1.39
5	0.86	1.12	1.23^{a}	1.30^{ab}	1.88	2.25
7	0.83	1.03	1.15^{abc}	1.06^{bc}	1.79	2.26
8	0.79	0.93	0.98^{bc}	1.10^{bc}	1.92	2.12
Levels						
0	0.82	1.14^{a}	1.20^{a}	1.30^{a}	2.18^{a}	2.20^{a}
1.30	0.79	0.93^{b}	0.95^{b}	1.01^{b}	1.34^{b}	1.76^{b}
Mean	0.81	1.05	1.09	1.17	1.80	2

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 32 Analysis of variance on coppice diameter at base level of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Levels	1	0.03	0.03	0.38^{ns}
	Provenances	6	0.45	0.08	1.00^{ns}
	Levels x provenances	6	0.35	0.06	0.77^{ns}
	Error	102	7.70	0.08	
2 months	Levels	1	1.25	1.25	11.95**
	Provenances	6	0.59	0.10	0.93^{ns}
	Levels x provenances	6	1.00	0.17	1.58^{ns}
	Error	101	10.59	0.10	
3 months	Levels	1	1.63	1.63	13.26**
	Provenances	6	1.73	0.29	2.35*
	Levels x provenances	6	0.79	0.13	1.08^{ns}
	Error	103	12.69	0.12	
4 months	Levels	1	2.59	2.59	17.17**
	Provenances	6	2.29	0.38	2.53*
	Levels x provenances	6	0.76	0.13	0.84^{ns}
	Error	105	15.83	0.15	
5 months	Levels	1	21.40	21.40	58.48**
	Provenances	6	3.81	0.63	1.73^{ns}
	Levels x provenances	6	1.72	0.29	0.78^{ns}
	Error	106	38.80	0.37	
6 months	Levels	1	6.48	6.48	7.91**
	Provenances	6	9.69	1.62	1.97^{ns}
	Levels x provenances	6	3.61	0.60	0.74^{ns}
	Error	105	86.03	0.82	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.2.8.3 Total height of coppice

Total height of coppice of Siamese Senna planted in provenance trials is shown in Table 33. At 1 month after planting, the average height of coppice was 69.93 cm. The highest height of coppice was 91.72 cm (Chaibadal, Lopburi provenance cut at 0 m). The lowest was 48.31 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest height of coppice for provenance was 84.40 cm (Chaibadal, Lopburi provenance) while the lowest was 56.93 cm (Takbai, Narathiwat provenance). Comparison between cut levels showed higher height of coppice at 0 m level (71.02 cm). The analysis of variance (Table 34) showed significant differences between provenances ($F=2.36^{*}$). The mean comparison by LSD separated provenances into 2 groups. At 2 months after planting, the average height of coppice was 106.40 cm. The highest height of coppice was 129.89 cm (Muang, Tak provenance cut at 0 m). The lowest was 76.34 cm (Potaram, Ratchaburi – seedlot 2000 provenance cut at 1.30 m). The highest height of coppice for provenance was 117.61 cm (Muang, Tak provenance) while the lowest was 93.68 cm (Ngao, Lampang provenance). Comparison between cut levels showed higher height of coppice at 0 m level (119.82 cm). The analysis of variance (Table 34) showed highly significant differences between levels ($F=21.59^{**}$) and significant differences between interaction of levels – provenances ($F=2.31^{*}$). At 3 months after planting, the average height of coppice was 115.95 cm. The highest height of coppice was 148.45 cm (Muang, Tak provenance cut at 0 m). The lowest was 74.81 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest height of coppice for provenance was 129.97 cm (Muang, Tak provenance) while the lowest was 103.98 cm (Ngao, Lampang provenance). Comparison between cut levels showed higher height of coppice at 0 m level (130.91 cm). The analysis of variance (Table 34) showed highly significant differences between levels ($F=24.81^{**}$). At 4 months after planting, the average height of coppice was 124.80 cm. The highest height of coppice was 171.84 cm (Muang, Tak provenance cut at 0 m). The lowest was 70.48 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest height of coppice for provenance was 142.13 cm (Muang, Tak provenance) while the lowest was 108.06 cm (Takbai, Narathiwat provenance). Comparison between cut levels showed higher height of coppice at 0 m level (146.38 cm). The analysis of variance (Table 34) showed highly significant differences between levels ($F=53.71^{**}$). At 5 months after planting, the average height of coppice was 173.07 cm. The highest height of coppice was 241.92 cm (Muang, Tak provenance cut at 0 m). The lowest was 92.41 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest height of coppice for provenance was 198.51 cm (Muang, Tak provenance) while the lowest was 150.35 cm (Ngao, Lampang provenance). Comparison between cut levels showed higher height of coppice at 0 m level (208.48 cm). The analysis of variance (Table 34) showed highly significant differences between levels ($F=44.66^{**}$). At 6 months after planting, the average height of coppice was 190.94 cm. The highest height of coppice was 260.68 cm (Muang, Tak provenance cut at 0 m). The lowest was 119.46 cm (Takbai, Narathiwat provenance cut at 1.30 m). The highest height of coppice for provenance was 219.83 cm (Muang, Tak provenance) while the lowest was 147.08 cm (Takbai, Narathiwat provenance). Comparison between cut levels showed higher height of coppice at 0 m level (223.67 cm). The analysis of variance (Table 34) showed highly significant differences between levels ($F=32.94^{**}$) and significant differences between provenances ($F=2.76^{*}$). The mean comparison by LSD separated provenances into 2 groups

The differences of coppice height among provenances were significant only in 1 and 6 months while among levels were significant since 2 to 6 months old. The height of coppice at 0 m cutting level was higher than at 1.30 m cutting level for all ages. The reason of this difference is similar to differences in DBL of coppice. At 0 m, the coppice was able to access to the water and nutrient in the root easier than at 1.30 m. In *E. camaldulensis* at 6 months old height of coppice was highest at 0 m cutting level while at 12 months old height of coppice was highest at 30 cm cutting level (Klumphabutr, 1994).

The coppicing had started immediately 1 month after cutting. At the older ages, number of coppice and diameter at base level of coppice was statistically insignificantly different while total height of coppice was statistically significantly different among provenances. The former parameters were controlled by the stump basal area while the latter parameter was not. These results suggest the suitable time of measurement for the other coppicing study in the future. If the study wants to observe the development of coppice, the measurement should be started from 1 month after cutting. If the study wants to detect the variation between provenances, the measurement priority can be emphasized at older age.

Table 33 Average coppice height of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Levels (m)/	Height (cm) at various months					
provenances	1	2	3	4	5	6
0/1	51.22	85.10	101.65	116.47	155.55	170.66
0/2	69.83	129.89	148.45	171.84	241.92	260.68
0/3	91.72	141.82	142.22	150.27	188.04	226.33
0/4	62.97	119.83	128.62	134.38	191.13	166.40
0/5	70.28	125.59	137.03	169.80	241.83	259.14
0/7	80.41	119.70	137.69	145.50	225.24	260.12
0/8	66.97	118.21	125.59	143.01	217.07	235.40
1.30/1	68.92	105.94	109.13	119.98	143.66	141.67
1.30/2	68.14	97.15	103.56	104.98	138.82	163.67
1.30/3	77.09	92.74	93.08	106.77	130.77	146.91
1.30/4	48.31	61.56	74.81	70.48	92.41	119.46
1.30/5	74.80	100.44	117.32	103.04	147.27	163.25
1.30/7	64.88	76.34	85.88	83.21	114.30	140.85
1.30/8	74.85	92.53	99.05	101.19	150.22	186.70
Provenances						
1	58.80^{b}	93.68	103.98	117.92	150.35	158.72^{bc}
2	69.24^{ab}	117.61	129.97	142.13	198.51	219.83^{a}
3	84.40^{a}	117.28	117.65	128.52	159.40	186.62^{abc}
4	56.93^{b}	95.84	106.46	108.06	150.48	147.08^{c}
5	72.72^{ab}	113.01	127.17	136.42	197.70	214.39^{a}
7	73.10^{ab}	100.73	113.31	116.19	173.03	200.49^{ab}
8	70.65^{ab}	106.22	113.98	124.72	183.65	212.67^{a}
Levels						
0	71.02	119.82^{a}	130.91^{a}	146.38^{a}	208.48^{a}	223.67^{a}
1.30	68.58	89.57^{b}	96.60^{b}	98.82^{b}	131.23^{b}	151.53^{b}
Mean	69.93	106.40	115.95	124.80	173.07	190.94

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 34 Analysis of variance on coppice height of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Levels	1	152.06	152.06	0.24^ns^
	Provenances	6	9,130.03	1,521.67	2.36*
	Levels x provenances	6	3,990.27	665.04	1.03^ns^
	Error	102	65,667.80	643.80	
2 months	Levels	1	25,886.82	25,886.82	21.59**
	Provenances	6	10,621.25	1,770.21	1.48^ns^
	Levels x provenances	6	16,601.77	2,766.96	2.31*
	Error	101	121,078.29	1,198.79	
3 months	Levels	1	32,441.41	32,441.41	24.81**
	Provenances	6	8,659.94	1,443.32	1.10^ns^
	Levels x provenances	6	11,333.69	1,888.95	1.44^ns^
	Error	103	134,694.83	1,307.72	
4 months	Levels	1	69,199.67	69,199.67	53.71**
	Provenances	6	15,978.01	2,663.00	2.07^ns^
	Levels x provenances	6	15,884.60	2,647.43	2.05^ns^
	Error	105	135,284.15	1,288.42	
5 months	Levels	1	177,114.33	177,114.33	44.66**
	Provenances	6	41,576.44	6,929.41	1.75^ns^
	Levels x provenances	6	30,157.59	5,026.27	1.27^ns^
	Error	106	420,361.12	3,965.67	
6 months	Levels	1	157,930.76	157,930.76	32.94**
	Provenances	6	79,457.62	13,242.94	2.76*
	Levels x provenances	6	26,326.81	4,387.80	0.92^ns^
	Error	105	503,390.52	4,794.20	

^ns^ Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

1.3 Molecular genetics

1.3.1 DNA extraction

The most popular protocol for DNA extraction from plant was CTAB extraction protocol by Doyle and Doyle (1987). However, the current study showed unacceptable DNA quality. The DNA result as detected by gel electrophoresis was not clean (Figure 10 - left). During the extraction process, the extracted solution was gelatinous-liked. This was different from the extraction in other species. The observation of specimen found that there was a red color in the young leave so it might contain some chemical substance, e.g. polysaccharide, which CTAB buffer could not remove. Porebski *et al.* (1997) stated that polysaccharides are visually evident in DNA extracted by their viscous, glue-like texture and make the DNA unmanageable in pipetting.

The extraction had changed the specimens from young leaves to buds in order to avoid the polysaccharides in leaves. Porebski *et al.* (1997) noted that mature leaves contains increased quantities of polyphenols, tannin and polysaccharides. However, the DNA yields were still not acceptable (Figure 10 – right).

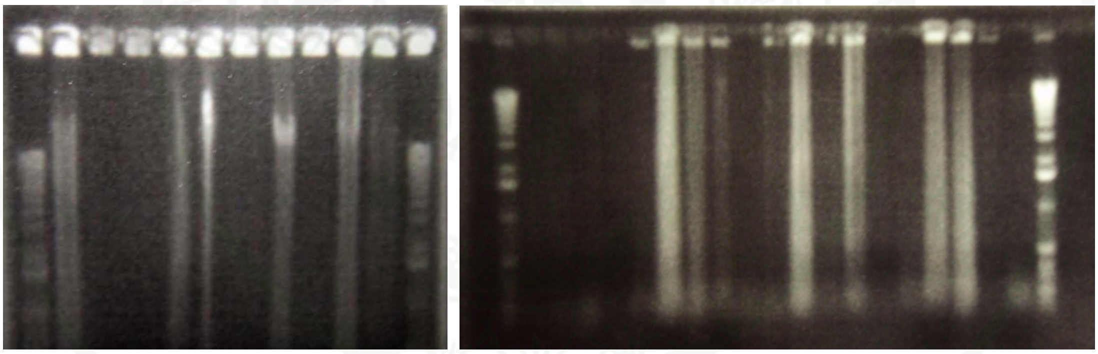

Figure 10 DNA extracted from young leaves (left) and buds (right) of Siamese Senna by CTAB extraction protocol.

The DNA extracted by sorbital buffer protocol with some modification gave the acceptable DNA quality (Figure 11). The new modified sorbital DNA extraction protocol was described, as follow;

The buds were used to avoid any polysaccharide which increase with the maturity. Kept the sample in the cold condition all the time. Grinded the buds with mortar and pestle with liquid nitrogen, transferred to 1.5 ml centrifuge tube and immediately added 1.3 ml of extraction buffer (0.1 M Tris-HCL [pH 7.5], 0.005 M EDTA [pH 8.0], 0.35 M sorbitol, 10 nM 2-mercaptoethanol). Incubated at room temperature for 20 minutes. Centrifuged for 5 min at 7,000 rpm at 20°C and split the supernatant. Dissolved pellet in 300 µl of extraction buffer and 300 µl of lysis buffer (0.2 M Tris-HCL [pH 7.5], 0.05 M EDTA [pH 8], 2 M NaCl, 2% CTAB), and swirled. Added 5 µl of RnaseA and incubated at 37°C for 60 minutes. Centrifuged for 10 min at 9,000 rpm at 20°C. Transferred the supernatant (~600 µl) into a new centrifuge tube. Extracted with phenol-chloroform-isoamyl alcohol (25:24:1) 700 µl, mixing gently but thoroughly. Centrifuged for 10 min at 9,000 rpm at 20°C. Transferred the supernatant (~600 µl) into a new centrifuge tube. Extracted with chloroform-isoamyl alcohol (24:1) 700 µl, mixing gently but thoroughly. Centrifuged for 10 min at 9,000 rpm at 20°C. Added 400 ml of isopropanol, mixed well, and precipitated DNA for 1 h or longer at -20°C. Centrifuged for 30 min at 10,000 rpm at 4°C, Gently poured off as much of the supernatant as possible without losing the precipitate, which will be a diffuse and very loose pellet. Add 200 µl of 80% EtOH directly to pellet and swirled gently. Centrifuged for 10 minutes, poured of supernatant carefully and allowed to air dry briefly at room temperature. Resuspended nucleic acid pellet in 1 ml TE (10 mM Tris-HCl, 1 mM EDTA, pH 7.4).

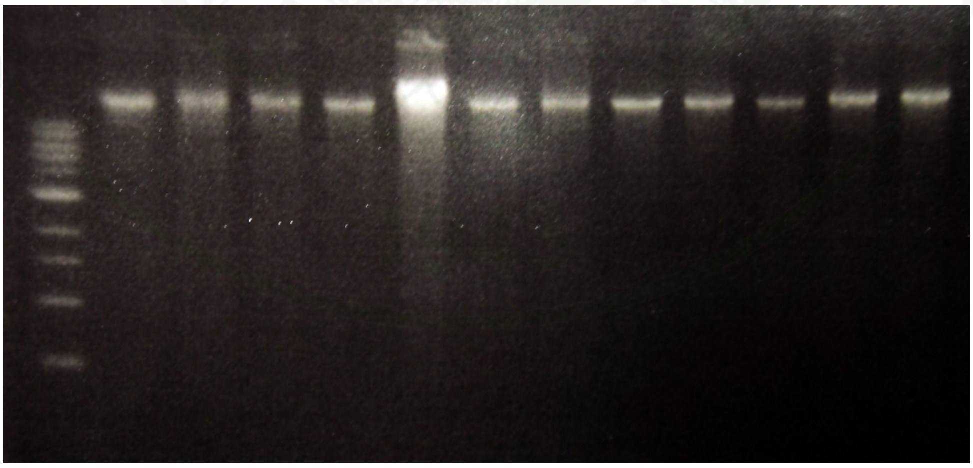

Figure 11 DNA extracted from buds of Siamese Senna by modified sorbital extraction protocol.

1.3.2 ISSR analysis

1.3.2.1 Genetic Diversity

Amplified bands ranging from 250 to 3,000 bp were scored as present (1) or absent (0). Statistical analysis was based on 53 amplified ISSR markers, and 5.9 bands were amplified on average by each primer (Table 35). Of the 53 bands, 90.57% (48) were polymorphic, with an average genetic diversity of 0.2620. The average genetic diversity and percentage of polymorphic loci for each provenance are summarized in Table 36. Some difference was observed among provenances with regard to the genetic variation indices, such as H_e and PPB. Provenance from Potaram, Ratchaburi had the highest PPB at 71.7%, and provenance from Ngao, Lampang had the lowest at 32.08%. Shanon's information index (I) ranged from 0.1722 to 0.3713 with the same trend line as PPB and H_e. The genetic variation indices at the species level were PPB = 90.57%, and I = 0.4033, much higher than the mean value of 9 provenances, especially the PPB (Table 36).

Table 35 Polymorphisms of ISSR bands amplified by the 9 ISSR primers

Primer sequence	Annealing temperature	Number of bands scored
CAA CAA CAA CAA CAA	54	5
ACT GAC TGA CTG ACT G	50	7
GAG GAG GAG GAG	50	4
GAC AGA CAG ACA GAC A	54	6
GAG AGA GAG AGA GAG AGA T	54	7
CTC TCT CTC TCT CTC TG	48	8
ACA CAC ACA CAC ACA CT	54	6
AGA GAG AGA GAG AGA GYC	45.5	4
ACA CAC ACA CAC ACA CYG	45.5	6
Average		5.9
Total		53

Table 36 Genetic diversity of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenance	N_p	PPB (%)	H_e	I
1	17	32.08	0.1163	0.1722
2	24	45.28	0.1345	0.2073
3	27	50.94	0.1874	0.2755
4	29	54.72	0.1796	0.2705
5	24	45.28	0.1400	0.2138
6	30	56.60	0.1955	0.2919
7	38	71.70	0.2455	0.3713
8	37	62.07	0.2461	0.3606
9	31	58.49	0.2049	0.3054
Mean	28.56	53.02	0.1833	0.2743
Species level	48	90.57	0.2620	0.4033
SD			0.1772	0.2339

Remarks: N_p: Number of polymorphic loci; PPB: Percentage of polymorphic loci; H_e: Nei's gene diversity; I: Shannon's information index.

Table 37 Nei's analysis of gene differentiation among provenances

	Nei's total gene diversity (H_t)	Nei's gene diversity in population (H_s)	Nei's genetic differentiatio n (G_{st})	Gene flow (N_m)
Mean value of loci	0.2551	0.1823	0.2852	1.2530
SD	0.0304	0.0184		

Finkeldey and Hattemer (2007) showed the results from many researches and group into low and high level genetic diversity. The H_e of low level group ranged from 0.017 to 0.058 while the high level ranged from 0.238 to 0.781. The current results showed that Siamese Senna in the provenance trials, which derived from seed source in various parts of Thailand, had a relatively moderate genetic diversity. This result may be reasonable due to the ability of this species in order to adapt to wide range of sites (Hassain, 1999) and also due to the large area of sample site from the North to the South. Genetic diversity also depends on ability of dispersal which is a very important factor (Vandewoestijne *et al.*, 2008).

Based on the value of Nei's total gene diversity (H_t = 0.2693) and Nei's gene diversity within populations (H_s = 0.1823), Nei's genetic differentiation (G_{st}) was calculated to be 0.2852 using Popgene software; that is 28% of gene differentiation occurred among provenances and 72% within provenances, which showed a relatively higher level of genetic differentiation within provenances. The average number of individuals exchanged between provenances per generation (N_m) was 1.2530 (Table 37).

1.3.2.2 Genetic Distance

Based on Nei's original genetic distance (Table 38), cluster analysis was carried out using UPGMA method and resulted in a dendrogram shown in Figure 12. The 9 provenances could be divided into 3 distinct groups. Group I was provenance from Muang, Kanchanaburi. Group II was provenance from the Northern region (Ngao, Lampang and Muang Tak). Group III was provenance from Central and

Southern regions (Takbai, Narathiwat; Potaram, Ratchaburi – seedlot 2000 and 2002; Chaibadal, Lopburi; Muaklek, Saraburi; Muang, Songkhla). This could be the result of geographic barriers which can prevent the exchange of genetic information and cause the differentiation among populations (Hao *et al.*, 2006). In group III, the natural barriers among Central and Southern regions could be low so gene flow between these 2 regions is possibly high. In addition, these 2 regions are influenced by the monsoon making these 2 regions moist than the other groups. Considering based on geographical distance, unusual genetic distance was found between Muaklek, Saraburi and Muang, Songkhla provenances. This could be due to the other reason, for example the trees in these 2 provenances were derived from the same seedlot and grown in the past. The similar result was reported in *Anthurium sinuatum* and *A. pentaphyllum* var. pentaphyllum in Brazil (Andrade *et al.*, 2009), the most genetically distant populations were relatively close geographically (46 km), whereas the most similar pairs were the most distant geographically (858 km).

Table 38 Genetic distance of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	1	2	3	4	5	6	7	8	9
1	****								
2	0.0829	****							
3	0.1759	0.1024	****						
4	0.1187	0.0992	0.0886	****					
5	0.1119	0.0823	0.0685	0.0787	****				
6	0.154	0.1757	0.1798	0.1617	0.127	****			
7	0.1191	0.1426	0.0791	0.0691	0.0637	0.1349	****		
8	0.1281	0.1007	0.095	0.0935	0.0624	0.1494	0.057	****	
9	0.1198	0.0836	0.0682	0.0926	0.0453	0.109	0.0919	0.0721	****

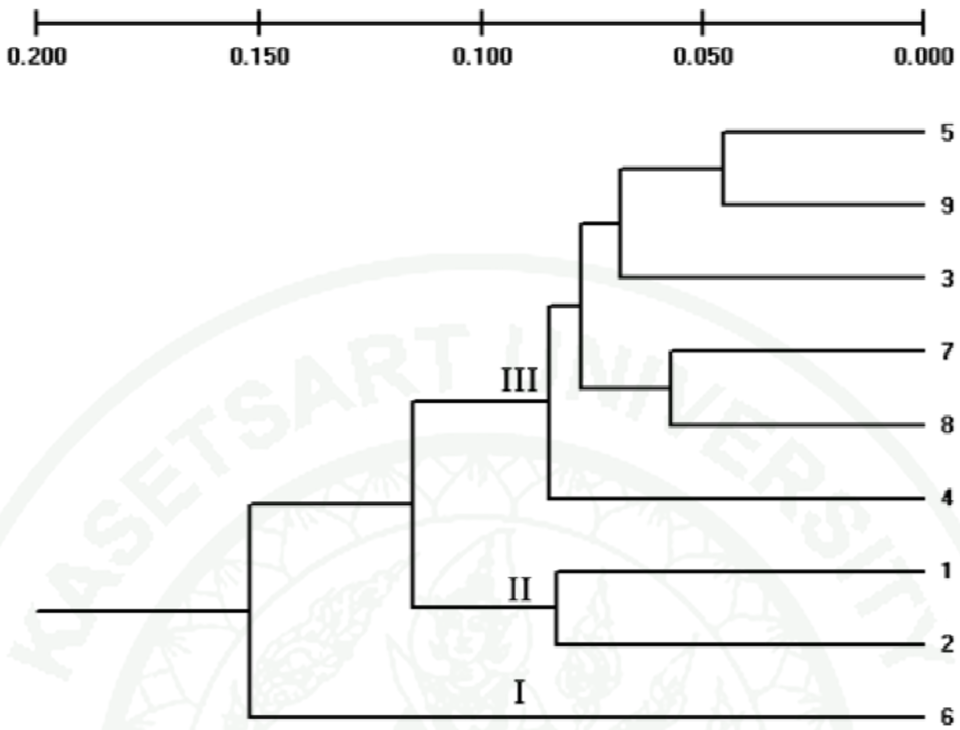

Figure 12 UPGMA dendrogram of Siamese Senna provenances based on ISSR markers.

2. Management practices

2.1 Provenance x fertilizer trials

Fertilizer application is one of the silvicultural practices aiming to increase the growth and production of tree. The current study selected 5 provenances from 9 available provenances to study due to the number of available seedlings.

2.1.1 Survival percentage

The survival percentages of provenance x fertilizer trials are shown in Table 39. At 1 month after planting, the average survival percentage was 70.42%. The highest were the pairs of Muaklek, Saraburi provenance – control and Potaram, Ratchaburi (seedlot 2002) provenance – control (91.67%) while the lowest were the pairs of Muang, Songkhla provenance – chemical fertilizer and Muang, Kanchanaburi provenance – mixed fertilizer (44.44%). The highest average survival percentage for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (82.64%) while the lowest was Muang, Kanchanburi provenance (57.64%). The highest survival percentage for fertilizer was control (82.64%) while the lowest was chemical fertilizer (57.64%). The analysis of variance (Table 40) showed highly significant differences in main effect both provenances ($F=4.84^{**}$) and fertilizers (5.21^{**}). The mean comparison by LSD separated both effects into 2 groups. After measurement at 1 month, damaged seedlings were replanted. At 2 months after planting, the average survival percentage increased to 93.06 percent. The highest was the pair of Muaklek, Saraburi provenance – manure fertilizer (100%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (75%). The highest average survival percentage for provenance was Muaklek, Saraburi provenance (97.22%) while the lowest was Muang, Kanchanburi provenance (84.72%). The highest survival percentage for fertilizer was control (95%) while the lowest was mixed fertilizer (90.56%). The analysis of variance (Table 40) showed significant differences only between provenances (main effect) ($F=3.31^{*}$). The mean comparison by LSD separated provenances into 2 groups. At 3 months after planting, the average survival percentage decreased to 92.92 percent. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – mixed fertilizer (100%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (75%). The highest average survival percentage for provenance was Muaklek, Saraburi provenance (96.53%) while the lowest was Muang, Kanchanburi provenance (84.03%). The highest survival percentage for fertilizer was manure fertilizer (93.89%) while the lowest were control and mixed fertilizer (92.22%). The analysis of variance (Table 40) showed significant differences only between provenances (main effect) ($F=3.59^{*}$). The mean comparison by LSD separated provenances into 2 groups. At 4 months after planting, the average survival percentage was 90 percent. The highest were the pairs of Muang, Kanchanaburi provenance – chemical fertilizer, Takbai, Narathiwat provenance – manure fertilizer and Muang, Songkhla provenance – manure fertilizer (97.22%) while the lowest was the pair of Muaklek, Saraburi provenance – manure fertilizer (61.11%). The highest average survival percentages for provenance were Takbai, Narathiwat and Muang, Songkhla provenances (93.75%) while the lowest was Muaklek, Saraburi provenance (79.86%). The highest survival percentages for fertilizer were chemical and manure fertilizers (91.67%) while the lowest was mixed fertilizer (86.67%). The analysis of variance (Table 40) showed highly significant differences only between provenances (main effect) ($F=4.40^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 5 months after planting, the average survival percentage was 90.1%. The highest were the pairs of Potaram, Ratchaburi (seedlot 2002) provenance – chemical fertilizer and Muaklek, Saraburi provenance – mixed fertilizer (97.22%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (69.44%). The highest average survival percentage for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (93.75%) while the lowest was Muang, Kanchanaburi provenance (81.25%). The highest survival percentage for fertilizer was manure fertilizer (91.67%) while the lowest was mixed fertilizer (88.89%). The analysis of variance (Table 40) showed significant differences only in provenances main effect ($F=3.33^{*}$). The mean comparison by LSD separated provenances into 2 groups. At 6 months after planting, the average survival percentage was 87.08 percent. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – chemical fertilizer (97.22%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (61.11%). The highest average survival percentage for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (90.97%) while the lowest was Muang, Kanchanaburi provenance (77.78%). The highest survival percentage for fertilizer was chemical fertilizer (88.89%) while the lowest was mixed fertilizer (84.44%). The analysis of variance (Table 40) showed significant differences only in provenances main effect ($F=2.64^{*}$). The mean comparison by LSD separated provenances into 2 groups. At 12 months after planting, the average survival percentage was 80.14 percent. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – chemical fertilizer (94.44%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (58.33%). The highest average survival percentage for provenance was Muaklek, Saraburi provenance (83.33%) while the lowest was Muang, Kanchanaburi provenance (75.69%). The highest survival percentage for fertilizer was chemical fertilizer (83.33%) while the lowest was mixed fertilizer (76.67%). The analysis of variance (Table 40) showed non-significant differences in all sources of variations. At

24 months after planting, the average survival percentage was 79.17 percent. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – chemical fertilizer (94.44%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (58.33%). The highest average survival percentage for provenance was Muaklek, Saraburi provenance (83.33%) while the lowest was Muang, Kanchanaburi provenance (73.61%). The highest survival percentage for fertilizer was chemical fertilizer (83.33%) while the lowest was mixed fertilizer (76.67%). The analysis of variance (Table 40) showed non-significant differences in all sources of variations. At 36 months after planting, the average survival percentage was 79.72 percent. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – chemical fertilizer (91.67%) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (55.56%). The highest average survival percentages for provenance were Muaklek, Saraburi provenance (84.03%) and Potaram, Ratchaburi (seedlot 2002) provenance (84.03%) while the lowest was Muang, Kanchanaburi provenance (75%). The highest survival percentage for fertilizer was chemical fertilizer (82.78%) while the lowest was mixed fertilizer (74.44%). The analysis of variance (Table 40) showed non-significant differences in all sources of variations.

Survival percentages of provenance x fertilizer trials were higher than in provenance trials at 1, 2, 3, 4, 5, 6 and 12 years old but lower at 24 and 36 years old. This could be the results of differences in site conditions (micro-climate) and the fertilizer effect. The quantity of fertilizers may also influence the survival percentage of the bigger trees as expressed at 24 and 36 months old (Table 14). Analysis of variance showed statistically difference among provenances in all first 6 months studied. This is similar to what observed in provenance trials indicating the effect of genetic controls from different provenances in the early growth. The better survival percentage make lower maintenance cost in the early stage for farmers. Analysis of variance among the fertilizer types showed significant difference only at 1 month old. Surprisingly, the best survival percentage was found for control treatment. This could be the effect of fertilizer on small seedlings. Instead of benefit to seedling, fertilizer may make some abrupt changes to chemical properties of soil resulting as mortality of seedling. Although there was no significant difference at 36 months old, chemical fertilizer seems to give the most survival percentage (82.78%). Moreover, when pairing chemical fertilizer with the Potaram, Ratchaburi (seedlot 2002) provenance the survival percentage was high up to 91.67% while the highest in provenance trials was only 90%.

Table 39 Average survival percentage of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/	Survival percentages (cm) at various ages (months)								
Provenances	1	2	3	4	5	6	12	24	36
Control/4	86.11	94.44	91.67	91.67	91.67	86.11	83.33	83.33	83.33
Control/5	91.67	97.22	94.44	91.67	86.11	86.11	77.78	77.78	77.78
Control/6	66.67	97.22	91.67	91.67	91.67	88.89	88.89	83.33	88.89
Control/8	91.67	94.44	91.67	83.33	91.67	88.89	80.56	83.33	83.33
Control/9	72.22	91.67	91.67	91.67	86.11	83.33	72.22	72.22	72.22
Chemical/4	66.67	91.67	91.67	91.67	91.67	91.67	75.00	77.78	80.56
Chemical /5	58.33	94.44	97.22	83.33	91.67	88.89	86.11	86.11	86.11
Chemical /6	52.78	86.11	86.11	97.22	80.56	77.78	77.78	77.78	77.78
Chemical /8	86.11	97.22	97.22	91.67	97.22	97.22	94.44	94.44	91.67
Chemical /9	44.44	94.44	94.44	94.44	91.67	88.89	83.33	80.56	77.78
Manure/4	80.56	97.22	97.22	97.22	94.44	88.89	86.11	86.11	83.33
Manure/5	83.33	100.00	97.22	83.33	94.44	91.67	86.11	86.11	86.11
Manure/6	66.67	80.56	83.33	86.11	83.33	83.33	77.78	75.00	77.78
Manure/8	83.33	97.22	94.44	94.44	91.67	88.89	75.00	72.22	80.56
Manure/9	66.67	94.44	97.22	97.22	94.44	88.89	75.00	66.67	75.00
Mixed/4	69.44	97.22	97.22	94.44	94.44	88.89	80.56	80.56	72.22
Mixed/5	69.44	97.22	97.22	61.11	97.22	94.44	83.33	83.33	86.11
Mixed/6	44.44	75.00	75.00	97.22	69.44	61.11	58.33	58.33	55.56
Mixed/8	69.44	97.22	100.00	88.89	94.44	88.89	80.56	77.78	80.56
Mixed/9	58.33	86.11	91.67	91.67	88.89	88.89	80.56	80.56	77.78

Table 39 (Continued)

Fertilizers/ Provenances	Survival percentages (cm) at various ages (months)								
	1	2	3	4	5	6	12	24	36
Provenances									
4	75.69[a]	95.14[a]	94.44[a]	93.75[a]	93.06[a]	88.89[a]	81.25	81.94	79.86
5	75.69[a]	97.22[a]	96.53[a]	79.86[b]	92.36[a]	90.28[a]	83.33	83.33	84.03
6	57.64[b]	84.72[b]	84.03[b]	93.06[a]	81.25[b]	77.78[b]	75.69	73.61	75.00
8	82.64[a]	96.53[a]	95.83[a]	89.58[a]	93.75[a]	90.97[a]	82.64	81.94	84.03
9	60.42[b]	91.67[b]	93.75[a]	93.75[a]	90.28[a]	87.50[a]	77.78	75.00	75.69
Fertilizers									
Control	81.67[a]	95.00	92.22	90.00	89.44	86.67	80.56	80.00	81.11
Chemical	61.67[b]	92.78	93.33	91.67	90.56	88.89	83.33	83.33	82.78
Manure	76.11[a]	93.89	93.89	91.67	91.67	88.33	80.00	77.22	80.56
Mixed	62.22[b]	90.56	92.22	86.67	88.89	84.44	76.67	76.11	74.44
Mean	70.42	93.06	92.92	90.00	90.14	87.08	80.14	79.17	79.72

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 40 Analysis of variance on survival percentage of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	794.78	264.93	0.68^{ns}
	Provenances	4	7,494.15	1,873.54	4.84^{**}
	Fertilizers	3	6,054.73	2,018.24	5.21^{**}
	Provenances x fertilizers	12	1,839.39	153.28	0.40^{ns}
	Error	57	22,078.52	387.34	
2 months	Blocks	3	104.93	34.98	0.28^{ns}
	Provenances	4	1,681.93	420.48	3.31^{*}
	Fertilizers	3	216.01	72.00	0.57^{ns}
	Provenances x fertilizers	12	1,218.86	101.57	0.80^{ns}
	Error	57	7,240.11	127.02	
3 months	Blocks	3	239.14	79.71	0.69^{ns}
	Provenances	4	1,657.25	414.31	3.59^{*}
	Fertilizers	3	41.65	13.88	0.12^{ns}
	Provenances x fertilizers	12	922.62	76.89	0.67^{ns}
	Error	57	6,581.32	115.46	
4 months	Blocks	3	123.48	41.16	0.32^{ns}
	Provenances	4	2,246.87	561.72	4.40^{**}
	Fertilizers	3	333.30	111.10	0.87^{ns}
	Provenances x fertilizers	12	2,505.94	208.83	1.63^{ns}
	Error	57	7,283.56	127.78	
5 months	Blocks	3	152.74	50.91	0.40^{ns}
	Provenances	4	1,688.11	422.03	3.33^{*}
	Fertilizers	3	91.02	30.34	0.24^{ns}
	Provenances x fertilizers	12	1,459.61	121.63	0.96^{ns}
	Error	57	7,223.05	126.72	
6 months	Blocks	3	128.11	42.70	0.24^{ns}
	Provenances	4	1,845.68	461.42	2.64^{*}
	Fertilizers	3	239.17	79.72	0.46^{ns}
	Provenances x fertilizers	12	2,006.09	167.17	0.96^{ns}
	Error	57	9,963.46	174.80	
12 months	Blocks	3	856.49	285.50	1.26^{ns}
	Provenances	4	688.36	172.09	0.76^{ns}
	Fertilizers	3	448.99	149.66	0.66^{ns}
	Provenances x fertilizers	12	3,076.90	256.41	1.13^{ns}
	Error	57	12,877.11	225.91	
24 months	Blocks	3	1,043.27	347.76	1.48^{ns}
	Provenances	4	1,296.29	324.07	1.38^{ns}
	Fertilizers	3	623.39	207.80	0.88^{ns}
	Provenances x fertilizers	12	2,740.72	228.39	0.97^{ns}

Table 40 (Continued)

Ages	Sources	DF	SS	MS	F
	Error	57	13,400.12	235.10	
36 months	Blocks	3	993.87	331.29	1.33^{ns}
	Provenances	4	1,210.00	302.50	1.22^{ns}
	Fertilizers	3	796.27	265.42	1.07^{ns}
	Provenances x fertilizers	12	2,506.27	208.86	0.84^{ns}
	Error	57	14,190.22	248.95	

^{ns} Non-significant difference, * Significant difference at 0.05 level,

** Significant difference at 0.01 level

2.1.2 Diameter at ground level (DGL)

The DGL of provenance x fertilizer trials are shown in Table 41. At 1 month after planting, the average DGL was 0.40 cm. The highest was the pair of Muaklek, Saraburi provenance – manure fertilizer (0.47 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.33 cm). The highest DGL for provenance were Muaklek, Saraburi provenance and Potaram, Ratchaburi (seedlot 2002) provenance (0.43 cm) while the lowest was Muang, Songkhla provenance (0.37 cm). The highest DGL for fertilizer was mixed fertilizer (0.41 cm) while the lowest were control and chemical fertilizer (0.39 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=10.38^{**}$) and between provenances ($F=6.13^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 2 months after planting, the average DGL was 0.43 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (0.54 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.35 cm). The highest DGL for provenance was Muaklek, Saraburi provenance (0.49 cm) while the lowest was Muang, Songkhla provenance (0.38 cm). The highest DGL for fertilizer was mixed fertilizer (0.46 cm) while the lowest was control (0.41 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=7.09^{**}$) and between provenances ($F=7.93^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 3 months after planting, the average DGL was 0.56 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (0.68 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.42 cm). The highest DGL for provenance were Muaklek, Saraburi provenance and Potaram, Ratchaburi (seedlot 2002) provenance (0.61 cm) while the lowest was Muang, Songkhla provenance (0.47 cm). The highest DGL for fertilizer was mixed fertilizer (0.58 cm) while the lowest was control (0.53 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=6.49^{**}$) and between provenances ($F=5.70^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 4 months after planting, the average DGL was 0.70 cm. The highest was the pair of Takbai, Narathiwat provenance – chemical fertilizer (0.87 cm) while the lowest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – manure fertilizer (0.51 cm). The highest DGL for provenance was Muang, Kanchanaburi provenance (0.77 cm) while the lowest was Potaram, Ratchaburi (seedlot 2002) provenance (0.58 cm). The highest DGL for fertilizer were chemical, manure and mixed fertilizer (0.71 cm) while the lowest was control (0.66 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=8.77^{**}$) and between provenances ($F=4.91^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 5 months after planting, the average DGL was 0.83 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (1 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.56 cm). The highest DGL for provenance was Muaklek, Saraburi provenance (0.90 cm) while the lowest was Muang, Songkhla provenance (0.67 cm). The highest DGL for fertilizer was chemical fertilizer (0.86 cm) while the lowest was control (0.76 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=6.73^{**}$) and between provenances ($F=4.34^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 6 months after planting, the average DGL was 0.87 cm. The highest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – manure fertilizer (1.07 cm) while the lowest was the pair of Muang Songkhla provenance – manure fertilizer (0.61 cm). The highest DGL for provenance was Muaklek, Saraburi provenance (0.96 cm) while the lowest was Muang Songkhla provenance (0.70 cm). The highest DGL for fertilizer were chemical, manure and mixed fertilizer (0.89 cm) while the lowest was control (0.81 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=9.89^{**}$) and between provenances ($F=3.75^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 12 months after planting, the average DGL was 2.13 cm. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (2.53 cm) while the lowest was the pair of Muang Songkhla provenance – manure fertilizer (1.75 cm). The highest DGL for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (2.25 cm) while the lowest was Muang Songkhla provenance (1.83 cm). The highest DGL for fertilizer was mixed fertilizer (2.18 cm) while the lowest was control (2.03 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=8.53^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 24 months after planting, the average DGL was 2.52 cm. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (3.09 cm) while the lowest was the pair of Muang Songkhla provenance – manure fertilizer (2.16 cm). The highest DGL for provenance was Muang, Kanchanaburi provenance (2.79 cm) while the lowest was Muang Songkhla provenance (2.24 cm). The highest DGL for fertilizer was chemical fertilizer (2.56 cm) while the lowest was control (2.46 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=13.79^{**}$) and between provenances ($F=3.70^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 36 months after planting, the average DGL was 3.78 cm. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (4.67 cm) while the lowest was the pair of Muang Songkhla provenance – manure fertilizer (3.09 cm). The highest DGL for provenance was Muang, Kanchanaburi provenance (4.22 cm) while the lowest was Muang Songkhla provenance (3.28 cm). The highest DGL for fertilizer was chemical fertilizer (3.84 cm) while the lowest was manure (3.71 cm). The analysis of variance (Table 42) showed highly significant differences between blocks ($F=13.75^{**}$) and between provenances ($F=5.62^{**}$). The mean comparison by LSD separated provenances into 3 groups.

The average DGL provenances x fertilizers trials were lower than in provenance trials in all age classes. This is the result of the fact that, these 2 trial sites were next to each other but those were on different aspects. So the site condition was the major factor for DGL growth difference in these 2 trials. There were significant variations among provenances in all age classes except at 12 months old. This is similar to the results in provenance trials indicating that there is a strong genetic control on this trait. At 36 months old, provenance from Muang, Kanchanaburi performed the best DGL growth. This is different from the survival percentage result. The worst trees were probably death during the development leaving the rest with high DGL. On the other hand, provenance from Muang, Kanchanaburi had ability to adapt well in this site. This can be confirmed by the result in provenance trials. The best 3 provenances performing well DGL growth were similar to this trial. There were no significant differences among fertilizer types. However, the highest value was found in the trees having chemical fertilizer. This is similar to the survival percentage result.

Table 41 Average diameter at ground level of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/	Diameter at ground level (cm) at various ages (months)								
Provenances	1	2	3	4	5	6	12	24	36
Control/4	0.39	0.43	0.57	0.71	0.81	0.88	2.18	2.42	3.48
Control/5	0.42	0.44	0.56	0.64	0.85	0.92	2.11	2.65	4.04
Control/6	0.38	0.36	0.50	0.69	0.73	0.79	2.15	2.69	4.08
Control/8	0.42	0.45	0.55	0.59	0.75	0.78	1.89	2.25	3.70
Control/9	0.36	0.38	0.46	0.69	0.65	0.68	1.81	2.30	3.35
Chemical/4	0.35	0.42	0.51	0.87	0.79	0.78	1.97	2.25	3.29
Chemical /5	0.44	0.54	0.68	0.71	1.00	1.03	2.14	2.44	3.69
Chemical /6	0.37	0.42	0.58	0.77	0.93	0.95	2.53	3.09	4.67
Chemical /8	0.42	0.45	0.60	0.56	0.93	1.00	2.31	2.85	4.38
Chemical /9	0.38	0.37	0.43	0.64	0.67	0.67	1.78	2.19	3.16
Manure/4	0.37	0.40	0.54	0.78	0.84	0.87	2.34	2.75	3.93
Manure/5	0.47	0.50	0.64	0.67	0.96	1.03	2.32	2.60	4.03
Manure/6	0.37	0.41	0.54	0.86	0.87	0.86	2.07	2.64	3.91
Manure/8	0.43	0.47	0.66	0.51	0.99	1.07	2.32	2.62	3.59
Manure/9	0.33	0.35	0.42	0.72	0.56	0.61	1.75	2.16	3.09
Mixed/4	0.39	0.41	0.56	0.68	0.84	0.91	2.25	2.55	3.99
Mixed/5	0.41	0.48	0.56	0.72	0.80	0.85	2.15	2.48	3.48
Mixed/6	0.41	0.47	0.59	0.77	0.87	0.89	2.09	2.73	4.22
Mixed/8	0.44	0.49	0.62	0.66	0.90	0.97	2.45	2.49	3.93
Mixed/9	0.39	0.43	0.56	0.69	0.78	0.85	1.97	2.31	3.53
Provenances									
4	0.38^{b}	0.41^{b}	0.54^{a}	0.76^{a}	0.82^{a}	0.86^{a}	2.18	2.49^{bc}	3.67^{bc}
5	0.43^{a}	0.49^{a}	0.61^{a}	0.69^{a}	0.90^{a}	0.96^{a}	2.18	2.54^{ab}	3.81^{b}
6	0.38^{b}	0.41^{b}	0.55^{a}	0.77^{a}	0.85^{a}	0.87^{a}	2.21	2.79^{a}	4.22^{a}
8	0.43^{a}	0.46^{a}	0.61^{a}	0.58^{b}	0.89^{a}	0.95^{a}	2.25	2.55^{ab}	3.90^{ab}
9	0.37^{b}	0.38^{b}	0.47^{b}	0.68^{a}	0.67^{b}	0.70^{b}	1.83	2.24^{c}	3.28^{c}
Fertilizers									
control	0.39	0.41	0.53	0.66	0.76	0.81	2.03	2.46	3.73
chemical	0.39	0.44	0.56	0.71	0.86	0.89	2.15	2.56	3.84
manure	0.40	0.42	0.56	0.71	0.84	0.89	2.16	2.55	3.71

Table 41 (Continued)

Fertilizers/	Diameter at ground level (cm) at various ages (months)								
Provenances	1	2	3	4	5	6	12	24	36
mixed	0.41	0.46	0.58	0.71	0.84	0.89	2.18	2.51	3.83
Mean	0.40	0.43	0.56	0.70	0.83	0.87	2.13	2.52	3.78

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 42 Analysis of variance on diameter at ground level of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	0.08	0.03	10.38^{**}
	Provenances	4	0.06	0.02	6.13^{**}
	Fertilizers	3	0.003	0.001	0.39^{ns}
	Provenances x fertilizers	12	0.02	0.002	0.75^{ns}
	Error	57	0.14	0.003	
2 months	Blocks	3	0.08	0.03	7.09^{**}
	Provenances	4	0.12	0.03	7.93^{**}
	Fertilizers	3	0.03	0.01	2.30^{ns}
	Provenances x fertilizers	12	0.04	0.003	0.95^{ns}
	Error	57	0.21	0.003	
3 months	Blocks	3	0.18	0.06	6.49^{**}
	Provenances	4	0.21	0.05	5.70^{**}
	Fertilizers	3	0.03	0.01	0.94^{ns}
	Provenances x fertilizers	12	0.13	0.01	1.16^{ns}
	Error	57	0.53	0.01	
4 months	Blocks	3	0.51	0.17	8.77^{**}
	Provenances	4	0.38	0.95	4.91^{**}
	Fertilizers	3	0.03	0.01	0.46^{ns}
	Provenances x fertilizers	12	0.19	0.02	0.82^{ns}
	Error	57	1.10	0.02	
5 months	Blocks	3	0.68	0.23	6.73^{**}
	Provenances	4	0.58	0.15	4.34^{**}
	Fertilizers	3	0.13	0.04	1.25
	Provenances x fertilizers	12	0.29	0.02	0.73
	Error	57	1.91	0.03	
6 months	Blocks	3	1.36	0.45	9.89^{**}
	Provenances	4	0.69	0.17	3.75^{**}
	Fertilizers	3	0.09	0.03	0.65^{ns}
	Provenances x fertilizers	12	0.41	0.03	0.75^{ns}
	Error	57	2.61	0.05	
12 months	Blocks	3	5.12	1.70	8.53^{**}
	Provenances	4	1.89	0.47	2.36^{ns}
	Fertilizers	3	0.27	0.09	0.45^{ns}
	Provenances x fertilizers	12	1.52	0.13	0.64^{ns}
	Error	57	11.41	0.20	
24 months	Blocks	3	6.82	2.27	13.79^{**}
	Provenances	4	2.44	0.61	3.70^{**}
	Fertilizers	3	0.13	0.04	0.26^{ns}
	Provenances x fertilizers	12	1.84	0.15	0.93^{ns}
	Error	57	9.39	0.16	
36 months	Blocks	3	13.76	4.59	13.75^{**}

Table 42 (Continued)

Ages	Sources	DF	SS	MS	F
	Provenances	4	7.49	1.87	5.62^{**}
	Fertilizers	3	0.28	0.09	0.28^{ns}
	Provenances x fertilizers	12	5.25	0.44	1.31^{ns}
	Error	57	19.01	0.33	

^{ns} Non-significant difference, * Significant difference at 0.05 level,

** Significant difference at 0.01 level

2.1.3 Total height

The total heights of provenance x fertilizer trials are shown in Table 43. At 1 month after planting, the average total height was 32.24 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (49.40 cm) while the lowest was the pair of Muang, Kanchanaburi provenance – mixed fertilizer (21.95 cm). The highest total height for provenance was Muaklek, Saraburi provenance (43.32 cm) while the lowest was Muang, Kanchanaburi provenance (25.86 cm). The highest total height for fertilizer was chemical fertilizer (34.03 cm) while the lowest was mixed fertilizer (30.79 cm). The analysis of variance (Table 44) showed highly significant differences in provenances ($F=27.71^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 2 months after planting, the average total height was 34.51 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (58.63 cm) while the lowest was the pair of Muang, Songkhla provenance – control (26.44 cm). The highest total height for provenance was Muaklek, Saraburi provenance (46.24 cm) while the lowest was Muang, Songkhla provenance (28.08 cm). The highest total height for fertilizer was chemical fertilizer (37.16 cm) while the lowest was control (32.77 cm). The analysis of variance (Table 44) showed highly significant differences between provenances ($F=26.73^{**}$), significant differences between fertilizers (2.95^{*}) and interaction of provenances-fertilizers (2.47^{*}). The mean comparison by LSD separated provenances into 3 groups and fertilizers into 2 groups. At 3 months after planting, the average total height was 40.03 cm. The highest was the pair of Muaklek, Saraburi provenance

– chemical fertilizer (62.25 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (27.94 cm). The highest total height for provenance was Muaklek, Saraburi provenance (51.79 cm) while the lowest was Muang, Songkhla provenance (31.32 cm). The highest total height for fertilizer was chemical fertilizer (42.43 cm) while the lowest was control (37.02 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (6.29^{**}) and between provenances ($F=25.36^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 4 months after planting, the average height was 45.99 cm. The total highest was the pair of Takbai, Narathiwat provenance – chemical fertilizer (69.08 cm) while the lowest was the pair of Potaram, Ratchaburi (seedlot 2002) provenance – manure fertilizer (29.96 cm). The highest total height for provenance was Takbai, Narathiwat provenance (56.81 cm) while the lowest was Potaram, Ratchaburi (seedlot 2002) provenance (34.77 cm). The highest total height for fertilizer was chemical fertilizer (49.39 cm) while the lowest was control (42.02 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (7.18^{**}) and between provenances ($F=12.34^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 5 months after planting, the average total height was 54.90 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (77.43 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (34.90 cm). The highest total height for provenance was Muaklek, Saraburi provenance (65.42 cm) while the lowest was Muang, Songkhla provenance (40.17 cm). The highest total height for fertilizer was chemical fertilizer (59.29 cm) while the lowest was control (50.61 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (5.47^{**}) and between provenances ($F=9.57^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 6 months after planting, the average total height was 57.17 cm. The highest was the pair of Muaklek, Saraburi provenance – chemical fertilizer (79.02 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (37.10 cm). The highest total height for provenance was Muaklek, Saraburi provenance (66.95 cm) while the lowest was Muang, Songkhla provenance (41.82 cm). The highest total height for fertilizer was chemical fertilizer (60.52 cm) while the lowest was control (53.30 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (6.02^{**}) and between provenances ($F=9.36^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 12 months after planting, the average total height was 119.30 cm. The highest was the pair of Muang, Kanchanburi provenance – chemical fertilizer (141.15 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (89.71 cm). The highest total height for provenance was Muaklek, Saraburi provenance (127.65 cm) while the lowest was Muang, Songkhla provenance (94.07 cm). The highest total height for fertilizer was chemical fertilizer (121.30 cm) while the lowest was control (118.33 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (7.14^{**}) and between provenances ($F=5.19^{**}$). The mean comparison by LSD separated provenances into 2 groups. At 24 months after planting, the average total height was 254.09 cm. The highest was the pair of Muang, Kanchanburi provenance – chemical fertilizer (312.40 cm) while the lowest was the pair of Muang, Songkhla provenance – chemical fertilizer (212.38 cm). The highest total height for provenance was Muang, Kanchanaburi provenance (282.27 cm) while the lowest was Muang, Songkhla provenance (214.14 cm). The highest total height for fertilizer was chemical fertilizer (260.54 cm) while the lowest was mixed fertilizer (245.48 cm). The analysis of variance (Table 44) showed highly significant differences between blocks (6.20^{**}) and between provenances ($F=6.21^{**}$). The mean comparison by LSD separated provenances into 3 groups. At 36 months after planting, the average total height was 381.63 cm. The highest was the pair of Muang, Kanchanburi provenance – chemical fertilizer (484.27 cm) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (296.41 cm). The highest total height for provenance was Muang, Kanchanaburi provenance (421.88 cm) while the lowest was Muang, Songkhla provenance (318.98 cm). The highest total height for fertilizer was chemical fertilizer (401.69 cm) while the lowest was mixed fertilizer (365.35 cm). The analysis of variance (Table 44) showed highly significant differences between provenances ($F=6.86^{**}$). The mean comparison by LSD separated provenances into 3 groups.

Differences in total height among provenances were significant in all measuring ages. Provenance from Takbai, Narathiwat; Muaklek, Saraburi; Muang

Kanchanaburi; Potaram, Ratchaburi (seedlot 2002) performed good total height. Their ranks were changes at different ages between each other. Provenance from Muang Songkhla showed the lowest total height at all ages, similar to the performances in provenance trials. Differences in total height between fertilizers were significant only at 2 months old, the other ages were not significantly different. Similar to DGL, chemical fertilizer seems to give the highest total height.

Table 43 Average height of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/	Height (cm) at various ages (months)								
Provenances	1	2	3	4	5	6	12	24	36
Control/4	25.33	28.63	35.89	48.52	50.80	57.17	129.22	248.76	349.11
Control/5	40.30	40.04	43.07	39.02	58.20	60.37	140.30	282.45	408.20
Control/6	29.46	29.60	34.04	47.23	48.98	52.33	117.44	276.39	416.80
Control/8	34.81	39.13	42.58	32.85	55.98	56.14	108.81	242.83	376.46
Control/9	24.59	26.44	29.53	42.50	39.07	40.48	95.87	217.68	332.32
Chemical/4	25.92	28.85	34.27	69.08	51.79	53.05	113.14	245.43	366.61
Chemical /5	49.40	58.63	62.25	45.55	77.43	79.02	123.15	251.70	388.39
Chemical /6	27.37	27.76	36.86	55.40	59.39	60.09	141.15	312.40	484.27
Chemical /8	38.51	41.65	47.41	35.28	67.23	70.13	138.96	280.79	446.57
Chemical /9	28.93	28.90	31.35	41.63	40.64	40.31	90.10	212.38	322.62
Manure/4	27.11	28.07	35.78	60.17	53.36	58.69	129.31	269.71	407.82
Manure/5	46.56	44.92	55.66	43.24	69.33	71.48	132.49	276.98	451.45
Manure/6	24.67	28.12	34.92	60.10	52.50	55.69	116.84	265.47	378.95
Manure/8	37.51	39.73	50.10	29.96	66.09	71.05	126.64	258.88	379.96
Manure/9	30.42	27.52	27.94	42.04	34.90	37.10	89.71	212.59	296.41
Mixed/4	28.09	29.12	34.69	49.47	49.88	54.53	125.00	242.74	363.08
Mixed/5	37.03	41.39	46.18	44.90	56.75	56.92	114.66	244.55	345.67
Mixed/6	21.95	29.94	36.07	49.81	55.39	54.37	121.34	274.82	407.50
Mixed/8	34.68	42.40	45.56	40.97	64.19	65.20	131.20	251.35	385.90
Mixed/9	32.18	29.45	36.45	42.11	46.07	49.38	100.61	213.92	324.58

Table 43 (Continued)

Fertilizers/ Provenances	Height (cm) at various ages (months)								
	1	2	3	4	5	6	12	24	36
Provenances									
4	26.62[c]	28.67[c]	35.16[c]	56.81[a]	51.46[b]	55.86[b]	124.17[a]	251.66[b]	371.66[b]
5	43.32[a]	46.24[a]	51.79[a]	43.18[b]	65.42[a]	66.95[a]	127.65[a]	263.92[ab]	398.43[ab]
6	25.86[c]	28.86[c]	35.47[c]	53.13[a]	54.06[b]	55.62[b]	124.19[a]	282.27[a]	421.88[a]
8	36.38[b]	40.73[b]	46.41[b]	34.77[c]	63.37[a]	65.63[a]	126.40[a]	258.46[ab]	397.22[ab]
9	29.03[c]	28.08[c]	31.32[c]	42.07[b]	40.17[c]	41.82[c]	94.07[b]	214.14[c]	318.98[c]
Fertilizers									
control	30.90	32.77[b]	37.02	42.02	50.61	53.30	118.33	253.62	376.58
chemical	34.03	37.16[a]	42.43	49.39	59.29	60.52	121.30	260.54	401.69
manure	33.25	33.67[b]	40.88	47.10	55.23	58.80	119.00	256.72	382.92
mixed	30.79	34.46[ab]	39.79	45.45	54.45	56.08	118.56	245.48	365.35
Mean	32.24	34.51	40.03	45.99	54.90	57.17	119.30	254.09	381.63

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 44 Analysis of variance on height of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Ages	Sources	DF	SS	MS	F
1 month	Blocks	3	96.17	32.06	1^{ns}
	Provenances	4	3,560.13	890.03	27.71^{**}
	Fertilizers	3	162.37	54.12	1.69^{ns}
	Provenances x fertilizers	12	538.61	44.88	1.40^{ns}
	Error	57	1,830.67	32.12	
2 months	Blocks	3	201.47	67.16	2.76^{ns}
	Provenances	4	4,540.08	1,135.02	46.73^{**}
	Fertilizers	3	215.06	71.67	2.95^{*}
	Provenances x fertilizers	12	720.70	60.06	2.47^{*}
	Error	57	1,384.43	24.29	
3 months	Blocks	3	891.05	297.02	6.29^{**}
	Provenances	4	4,791.15	1,197.79	25.36^{**}
	Fertilizers	3	311.73	103.91	2.20^{ns}
	Provenances x fertilizers	12	926.23	77.19	1.63^{ns}
	Error	57	2,692.29	47.23	
4 months	Blocks	3	2,216.21	738.74	7.18^{**}
	Provenances	4	5,077.76	1,269.44	12.34^{**}
	Fertilizers	3	576.09	192.03	1.87^{ns}
	Provenances x fertilizers	12	1,326.98	110.58	1.07^{ns}
	Error	57	5,864.11	102.88	
5 months	Blocks	3	2,829.78	943.26	5.47^{**}
	Provenances	4	6,593.52	1,648.38	9.57^{**}
	Fertilizers	3	760.69	253.57	1.47^{ns}
	Provenances x fertilizers	12	1,213.08	253.57	0.59^{ns}
	Error	57	9,822.58	172.33	
6 months	Blocks	3	3,139.01	1,046.34	6.02^{**}
	Provenances	4	6,511.71	1,627.93	9.36^{**}
	Fertilizers	3	601.49	200.50	1.15^{ns}
	Provenances x fertilizers	12	1,738.35	144.86	0.83^{ns}
	Error	57	9,913.64	173.92	
12 months	Blocks	3	13,285.87	4,428.62	7.14^{**}
	Provenances	4	12,869.25	3,217.31	5.19^{**}
	Fertilizers	3	111.43	37.14	0.06^{ns}
	Provenances x fertilizers	12	5,942.16	495.18	0.80^{ns}
	Error	57	35,364.92	620.44	
24 months	Blocks	3	30,135.84	10,045.28	6.20^{**}
	Provenances	4	40,184.75	10,046.19	6.21^{**}
	Fertilizers	3	2,459.58	819.86	0.51^{ns}
	Provenances x fertilizers	12	11,872.19	989.35	0.61^{ns}
	Error	57	92,280.22	1,618.95	
36 months	Blocks	3	28,283.63	9,427.88	2.62^{ns}
	Provenances	4	98,713.92	24,678.48	6.86^{**}

Table 44 (Continued)

Ages	Sources	DF	SS	MS	F
	Fertilizers	3	13,894.50	4,631.50	1.29^{ns}
	Provenances x fertilizers	12	56,899.07	4,741.59	1.32^{ns}
	Error	57	205,011.84	3,596.70	

^{ns} Non-significant difference, * Significant difference at 0.05 level,

** Significant difference at 0.01 level

2.1.4 Relative growth rate of diameter at ground level (RDGL)

The RDGL provenance x fertilizer trials are shown in Table 45. During 1-36 months old, the average RDGL was 0.06 cm/cm/month ranging between 0.06 and 0.07 cm/cm/month. The highest RDGL for provenance was Muaklek, Saraburi provenance (0.07 cm/cm/month) while the other provenances were 0.06 cm/cm/month. There were no differences in RDGL for fertilizer. All types of fertilizer were 0.06 cm/cm/month. The analysis of variance (Table 46) showed significant differences among blocks ($F=3^{*}$) and highly significant difference among provenances ($F=4.31^{**}$). The mean comparison by LSD separated provenances into 2 groups. During 1-12 months old, the average RDGL was 0.15 cm/cm/month ranging between 0.14 and 0.17 cm/cm/month. The highest RDGL for provenance were Takbai, Narathiwat and Muang, Kanchanaburi provenances (0.16 cm/cm/month) while the lowest was Muaklek, Saraburi provenance (0.14 cm/cm/month). There were no differences in RDGL for fertilizer. All types of fertilizer had RDGL at 0.15 cm/cm/month. The analysis of variance (Table 46) showed highly significant differences among blocks ($F=6.09^{**}$) while the others showed no significant differences. At the second stage of growing, during 12-24 months old, the average RDGL was 0.01 cm/cm/month ranging between 0.01 and 0.02 cm/cm/month. The highest RDGL for provenance were Muang, Kanchanaburi and Muang, Songkhla provenances (0.02 cm/cm/month) while the other provenances were 0.01 cm/cm/month. The highest RDGL for fertilizer were control and manure fertilizer (0.02 cm/cm/month) while the other fertilizers were 0.01 cm/cm/month. The analysis of variance (Table 46) showed no significant differences in all sources of variations. At the third stage of growing, during 24-36 months old, the average RDGL was 0.03 cm/cm/month ranging between 0.03 and 0.04 cm/cm/month. The highest RDGL for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (0.04 cm/cm/month) while the other provenances were 0.03 cm/cm/month. The highest RDGL for fertilizer was mixed fertilizer (0.04 cm/cm/month) while the other fertilizers were 0.03 cm/cm/month. The analysis of variance (Table 46) showed highly significant difference among blocks ($F=5.21^{**}$) while the other sources of variation showed no significant differences.

The analysis of variance showed no significant differences among provenances in all growing stages except in the overall stage. Provenance from Muang, Kanchanaburi performed the best RDGL. This is similar to the result in provenance trials. Differences in RDGL among fertilizer types were not significant in all growing stages. The trend of RDGL, which highest in the 1st growing stage, decreases in the 2nd growing stage and increase in the 3rd growing stage, was similar the provenance trials.

Table 45 Average diameter at ground level relative growth rate of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/	Relative growth rate (cm/cm/month) at various stages (months)			
Provenances	Overall	1-12	12-24	24-36
Control/4	0.06	0.16	0.01	0.03
Control/5	0.06	0.15	0.02	0.04
Control/6	0.07	0.16	0.02	0.04
Control/8	0.06	0.14	0.01	0.04
Control/9	0.06	0.15	0.02	0.03
Chemical/4	0.06	0.16	0.01	0.03
Chemical /5	0.06	0.14	0.01	0.03
Chemical /6	0.07	0.17	0.02	0.03
Chemical /8	0.07	0.15	0.02	0.04
Chemical /9	0.06	0.14	0.02	0.03
Manure/4	0.07	0.16	0.02	0.03
Manure/5	0.06	0.14	0.01	0.04
Manure/6	0.07	0.16	0.02	0.03
Manure/8	0.06	0.15	0.01	0.03
Manure/9	0.06	0.15	0.02	0.03
Mixed/4	0.07	0.16	0.01	0.04
Mixed/5	0.06	0.15	0.01	0.03
Mixed/6	0.07	0.14	0.02	0.04
Mixed/8	0.06	0.16	0.00	0.04
Mixed/9	0.06	0.15	0.01	0.04
Provenances				
4	0.06^{b}	0.16	0.01	0.03
5	0.06^{b}	0.14	0.01	0.03
6	0.07^{a}	0.16	0.02	0.03
8	0.06^{b}	0.15	0.01	0.04
9	0.06^{b}	0.15	0.02	0.03
Fertilizers				
control	0.06	0.15	0.02	0.03
chemical	0.06	0.15	0.01	0.03
manure	0.06	0.15	0.02	0.03
mixed	0.06	0.15	0.01	0.04
Mean	0.06	0.15	0.01	0.03

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 46 Analysis of variance on diameter at ground level relative growth rate of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Stages	Sources	DF	SS	MS	F
Overall	Blocks	3	$2.5x10^{-4}$	$8.3x10^{-5}$	3^{*}
	Provenances	4	$4.7x10^{-4}$	$1.2x10^{-4}$	4.31^{**}
	Fertilizers	3	$4.5x10^{-6}$	$1.5x10^{-6}$	0.05^{ns}
	Provenances x fertilizers	12	$2.8x10^{-4}$	$2.4x10^{-5}$	0.86^{ns}
	Error	57	$1.6x10^{-3}$	$2.8x10^{-5}$	
1-12 months	Blocks	3	$6.2x10^{-3}$	$2.1x10^{-3}$	6.09^{**}
	Provenances	4	$2.8x10^{-3}$	$7.1x10^{-4}$	2.08^{ns}
	Fertilizers	3	$2.5x10^{-4}$	$8.2x10^{-5}$	0.24^{ns}
	Provenances x fertilizers	12	$3x10^{-3}$	$2.5x10^{-4}$	0.73^{ns}
	Error	57	0.02	$3.4x10^{-4}$	
12-24 months	Blocks	3	$7.5x10^{-4}$	$2.5x10^{-4}$	2.08^{ns}
	Provenances	4	$1.1x10^{-3}$	$2.9x10^{-4}$	2.42^{ns}
	Fertilizers	3	$1.9x10^{-4}$	$6.3x10^{-5}$	0.53^{ns}
	Provenances x fertilizers	12	$8.4x10^{-4}$	$7x10^{-5}$	0.58^{ns}
	Error	57	$6.8x10^{-3}$	$1.2x10^{-4}$	
24-36 months	Blocks	3	$6.7x10^{-4}$	$2.2x10^{-4}$	5.21^{**}
	Provenances	4	$1.9x10^{-4}$	$4.8x10^{-5}$	1.13^{ns}
	Fertilizers	3	$1.7x10^{-4}$	$5.7x10^{-5}$	1.35^{ns}
	Provenances x fertilizers	12	$8.6x10^{-4}$	$7.1x10^{-5}$	1.67^{ns}
	Error	57	$2.4x10^{-3}$	$4.3x10^{-5}$	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

2.1.5 Relative growth rate of total height

The total height relative growth rates of provenance x fertilizer trials are shown in Table 47. During 1-36 months old, the average relative growth rate of total height was 0.07 cm/cm/month ranging between 0.06 and 0.08 cm/cm/month. The highest total height relative growth rate for provenance was Muang, Kanchanaburi provenance (0.07 cm/cm/month) while the other provenances were

0.06 cm/cm/month. There were no differences in total height relative growth rate for fertilizer. All types of fertilizer were 0.07 cm/cm/month. The analysis of variance (Table 48) showed highly significant difference among provenances ($F=15.36^{**}$). The mean comparison by LSD separated provenances into 4 groups. During 1-12 months old, the average relative growth rate of total height was 0.12 cm/cm/month ranging between 0.08 cm/cm/month (Muaklek, Saraburi provenance – chemical fertilizer) and 0.16 cm/cm/month (Muang, Kanchanaburi provenance – mixed fertilizer). The highest total height relative growth rates for provenance were Takbai, Narathiwat and Muang, Kanchanaburi provenances (0.16 cm/cm/month) while the lowest was Muaklek, Saraburi provenance (0.14 cm/cm/month). There were no differences in total height relative growth rate for fertilizer. All types of fertilizer had total height relative growth rate at 0.12 cm/cm/month. The analysis of variance (Table 48) showed highly significant differences among blocks ($F=6.38^{**}$) and provenances (13.05^{**}). The mean comparison by LSD separated provenances into 3 groups. At the second stage of growing, during 12-24 months old, the average relative growth rate of total height was 0.06 cm/cm/month ranging between 0.05 and 0.07 cm/cm/month. The highest total height relative growth rates for provenance were Muang, Kanchanaburi and Muang, Songkhla provenances (0.07 cm/cm/month) while the other provenances were 0.06 cm/cm/month. The highest total height relative growth rate for fertilizer was manure fertilizer (0.07 cm/cm/month) while the other fertilizers were 0.06 cm/cm/month. The analysis of variance (Table 48) showed highly significant differences among blocks ($F=5.24^{**}$) and high significant difference among provenances (3.18^{*}). The mean comparison by LSD separated provenances into 3 groups. At the third stage of growing, during 24-36 months old, the average relative growth rate of total height was 0.03 cm/cm/month ranging between 0.03 and 0.04 cm/cm/month. The highest total height relative growth rate for provenance was Potaram, Ratchaburi (seedlot 2002) provenance (0.04 cm/cm/month) while the other provenances were 0.03 cm/cm/month. The highest total height relative growth rate for fertilizer was chemical fertilizer (0.04 cm/cm/month) while the other fertilizers were 0.03 cm/cm/month. The analysis of variance (Table 23) showed highly significant difference among blocks ($F=4.36^{**}$) while the other sources of variation showed non-significant differences.

The analysis of variance showed significant among provenances in all growing stages except the 3rd growing stage. Provenance from Muang, kanchanaburi showed the highest relative growth rate of height. This is similar to relative growth rate of height result in the provenance trials. Differences in relative growth rate of height among fertilizer types were not significant in all growing stages.

Table 47 Average height relative growth rate of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/	Relative growth rate (cm/cm/month) at various stages (months)			
Provenances	Overall	1-12	12-24	24-36
Control/4	0.08	0.15	0.06	0.03
Control/5	0.07	0.11	0.06	0.03
Control/6	0.08	0.13	0.07	0.03
Control/8	0.07	0.10	0.07	0.04
Control/9	0.07	0.12	0.07	0.04
Chemical/4	0.08	0.14	0.06	0.03
Chemical /5	0.06	0.08	0.06	0.04
Chemical /6	0.08	0.15	0.07	0.04
Chemical /8	0.07	0.12	0.06	0.04
Chemical /9	0.07	0.10	0.07	0.03
Manure/4	0.08	0.14	0.06	0.03
Manure/5	0.07	0.09	0.06	0.04
Manure/6	0.08	0.14	0.07	0.03
Manure/8	0.07	0.11	0.06	0.03
Manure/9	0.07	0.10	0.07	0.03
Mixed/4	0.07	0.13	0.06	0.03
Mixed/5	0.06	0.10	0.06	0.03
Mixed/6	0.08	0.16	0.07	0.03
Mixed/8	0.07	0.12	0.05	0.04
Mixed/9	0.07	0.10	0.06	0.04
Provenances				
4	0.06^{b}	0.16^{a}	0.06^{c}	0.03
5	0.06^{d}	0.14^{c}	0.06^{bc}	0.03
6	0.07^{a}	0.16^{a}	0.07^{a}	0.03
8	0.06^{c}	0.15^{b}	0.06^{c}	0.04
9	0.06^{c}	0.15^{bc}	0.07^{ab}	0.03
Fertilizers				
control	0.07	0.12	0.06	0.03
chemical	0.07	0.12	0.06	0.04
manure	0.07	0.12	0.07	0.03
mixed	0.07	0.12	0.06	0.03
Mean	0.07	0.12	0.06	0.03

Mean values followed by the same letter are not significantly different at $P < 0.05$ according to least significant difference

Table 48 Analysis of variance on height relative growth rate of provenance x fertilizer trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Stages	Sources	DF	SS	MS	F
Overall	Blocks	3	$3.5x10^{-4}$	$1.2x10^{-4}$	2.54^{ns}
	Provenances	4	$2.8x10^{-3}$	$7x10^{-4}$	15.36^{**}
	Fertilizers	3	$2.8x10^{-5}$	$9.2x10^{-6}$	0.2^{ns}
	Provenances x fertilizers	12	$5.2x10^{-4}$	$4.3x10^{-5}$	0.95^{ns}
	Error	57	$2.6x10^{-3}$	$4.5x10^{-5}$	
1-12 months	Blocks	3	$9.7x10^{-3}$	$3.2x10^{-3}$	6.38^{**}
	Provenances	4	0.03	$6.6x10^{-3}$	13.05^{**}
	Fertilizers	3	$1x10^{-3}$	$3.4x10^{-4}$	0.67^{ns}
	Provenances x fertilizers	12	$5.7x10^{-3}$	$4.8x10^{-4}$	0.94^{ns}
	Error	57	0.29	$5.1x10^{-4}$	
12-24 months	Blocks	3	$2x10^{-3}$	$6.7x10^{-4}$	5.24^{**}
	Provenances	4	$1.6x10^{-3}$	$4x10^{-4}$	3.18^{*}
	Fertilizers	3	$2.5x10^{-4}$	$8.2x10^{-5}$	0.64^{ns}
	Provenances x fertilizers	12	$6.9x10^{-4}$	$5.7x10^{-5}$	0.45^{ns}
	Error	57	$7.2x10^{-3}$	$1.3x10^{-4}$	
24-36 months	Blocks	3	$7.6x10^{-4}$	$2.5x10^{-4}$	4.36^{**}
	Provenances	4	$6.9x10^{-5}$	$1.7x10^{-5}$	0.29^{ns}
	Fertilizers	3	$8.7x10^{-5}$	$2.9x10^{-5}$	0.5^{ns}
	Provenances x fertilizers	12	$8x10^{-4}$	$6.7x10^{-5}$	1.15^{ns}
	Error	57	$3.3x10^{-3}$	$5.8x10^{-5}$	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

2.1.6 Biomass in provenance x fertilizer trials

The allometric equations used in provenance x fertilizer trials were derived from the provenance trials. Because both trials were located in the same area and planted in the same time therefore the equations were transferable.

2.1.6.1 Biomass at 24 months old

Biomass of tree in the provenance x fertilizer trials at 24 months old was calculated by using the allometric equations at 24 months old (Table 16). The results are shown in Table 49. The average biomass of stem was 0.94 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (1.51 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.60 ton/hectare). The highest average biomass of stem for provenance was Muang, Kanchanaburi provenance (1.16 ton/hectare) while the lowest was Muang, Songkhla provenance (0.66 ton/hectare). The highest average biomass of stem for fertilizer was chemical fertilizer (1.01 ton/hectare) while the lowest was mixed fertilizer (0.89 ton/hectare). The average biomass of leaves was 0.57 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (0.91 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.36 ton/hectare). The highest average biomass of leaves for provenance was Muang, Kanchanaburi provenance (0.72 ton/hectare) while the lowest was Muang, Songkhla provenance (0.41 ton/hectare). The highest average biomass of leaves for fertilizer was chemical fertilizer (0.62 ton/hectare) while the lowest was mixed and control fertilizers (0.54 ton/hectare). The average biomass of branches was 0.46 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (0.72 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.30 ton/hectare). The highest average biomass of branches for provenance was Muang, Kanchanaburi provenance (0.58 ton/hectare) while the lowest was Muang, Songkhla provenance (0.33 ton/hectare). The highest average biomass of branches for fertilizer was chemical fertilizer (0.50 ton/hectare) while the lowest was mixed fertilizer (0.43 ton/hectare). The average biomass of all parts was 1.93 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (3.06 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (1.19 ton/hectare). The highest average biomass of all parts for provenance was Muang, Kanchanaburi provenance (2.44 ton/hectare) while the lowest was Muang, Songkhla provenance (1.35 ton/hectare). The highest average biomass of all parts for fertilizer was chemical fertilizer (2.09 ton/hectare) while the lowest was mixed fertilizer (1.80 ton/hectare).

The analysis of variance for all components (Table 50) showed significant differences between block ($F=10.48\text{-}10.70^{**}$) and provenances (main effect) ($F=3.80\text{-}3.98^{**}$). The mean comparison by LSD separated provenances into 2 groups. Although no significant differences were found among fertilizer types, the highest biomass was in the tree received chemical fertilizer.

Table 49 Biomass of provenance x fertilizer trials Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/ Provenances	Biomass (ton/hectare)			
	Stem	Leaves	Branches	Total
Control/4	0.83	0.50	0.40	1.67
Control/5	1.14	0.68	0.54	2.30
Control/6	1.15	0.69	0.55	2.32
Control/8	0.75	0.45	0.36	1.49
Control/9	0.66	0.39	0.32	1.31
Chemical/4	0.86	0.52	0.41	1.74
Chemical /5	0.88	0.53	0.43	1.78
Chemical /6	1.51	0.91	0.72	3.06
Chemical /8	1.21	0.72	0.58	2.44
Chemical /9	0.72	0.43	0.35	1.43
Manure/4	1.13	0.68	0.54	2.28
Manure/5	1.03	0.62	0.50	2.07
Manure/6	1.01	0.61	0.49	2.04
Manure/8	1.06	0.63	0.50	2.14
Manure/9	0.60	0.36	0.30	1.19
Mixed/4	0.89	0.54	0.43	1.80
Mixed/5	0.87	0.52	0.42	1.74
Mixed/6	0.91	0.54	0.44	1.82
Mixed/8	1.13	0.68	0.54	2.29
Mixed/9	0.91	0.55	0.44	1.83
Provenances				
4	0.92^{ab}	0.56	0.45	1.86
5	0.98^{a}	0.59	0.47	1.99
6	1.16^{a}	0.72	0.58	2.44
8	0.99^{a}	0.59	0.47	1.99
9	0.66^{b}	0.41	0.33	1.35
Fertilizers				
control	0.91	0.54	0.44	1.82
chemical	1.01	0.62	0.50	2.09
manure	0.96	0.59	0.47	1.97
mixed	0.89	0.54	0.43	1.80
Mean	0.94	0.57	0.46	1.93

Remarks: The mean comparisons as shown in letter are similar for all components due to the same parameters, including DGL and total height at the same age, were used in all allometric equations.

Table 50 Analysis of variance on biomass of provenance x fertilizer trials of Siamese Senna at 24 months old in Lad Krating Plantation, Chachoengsao established in 2006

Components	Sources	DF	SS	MS	F
Stem	Blocks	3	4.44	1.48	10.60^{**}
	Provenances	4	2.15	0.54	3.85^{**}
	Fertilizers	3	0.17	0.06	0.41^{ns}
	Provenances x fertilizers	12	1.21	0.10	0.72^{ns}
	Error	57	7.96	0.14	
Leaves	Blocks	3	1.61	0.54	10.58^{**}
	Provenances	4	0.78	0.19	3.85^{**}
	Fertilizers	3	0.06	0.02	0.42^{ns}
	Provenances x fertilizers	12	0.44	0.04	0.72^{ns}
	Error	57	2.88	0.05	
Branches	Blocks	3	0.96	0.32	10.70^{**}
	Provenances	4	0.47	0.12	3.98^{**}
	Fertilizers	3	0.03	0.01	0.38^{ns}
	Provenances x fertilizers	12	0.26	0.02	0.72^{ns}
	Error	57	1.70	0.03	
Total	Blocks	3	18.82	6.27	10.48^{**}
	Provenances	4	9.10	2.27	3.80^{**}
	Fertilizers	3	0.72	0.24	0.40^{ns}
	Provenances x fertilizers	12	5.14	0.43	0.72^{ns}
	Error	57	34.13	0.60	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

2.1.6.2 Biomass at 36 months old

Biomass of tree in the provenance x fertilizer trials at 36 months old was calculated by using the allometric equations at 36 months old (Table 18). The results are shown in Table 51. The average biomass of stem was 2.35 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (4.02 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (1.18 ton/hectare). The highest average biomass of stem for provenance was Muang, Kanchanaburi provenance (2.98 ton/hectare) while the lowest was Muang, Songkhla provenance (1.58 ton/hectare). The highest average biomass of stem for fertilizer was chemical fertilizer (2.70 ton/hectare) while the lowest was mixed fertilizer (2.12 ton/hectare). The average biomass of leaves was 0.47 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (0.83 kg) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.22 ton/hectare). The highest average biomass of leaves for provenance was Muang, Kanchanaburi provenance (0.61 ton/hectare) while the lowest was Muang, Songkhla provenance (0.31 ton/hectare). The highest average biomass of leaves for fertilizer was chemical fertilizer (0.55 ton/hectare) while the lowest was mixed fertilizer (0.42 ton/hectare). The average biomass of branches was 0.32 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (0.62 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (0.13 ton/hectare). The highest average biomass of branches for provenance was Muang, Kanchanaburi provenance (0.42 ton/hectare) while the lowest was Muang, Songkhla provenance (0.19 ton/hectare). The highest average biomass of branches for fertilizer was chemical fertilizer (0.39 ton/hectare) while the lowest was mixed fertilizer (0.27 ton/hectare). The average biomass of all parts was 3.38 ton/hectare. The highest was the pair of Muang, Kanchanaburi provenance – chemical fertilizer (6.05 ton/hectare) while the lowest was the pair of Muang, Songkhla provenance – manure fertilizer (1.55 ton/hectare). The highest average biomass of all parts for provenance was Muang, Kanchanaburi provenance (4.36 ton/hectare) while the lowest was Muang, Songkhla provenance (32.16 ton/hectare). The highest average biomass of all parts for fertilizer was chemical fertilizer (3.97 ton/hectare) while the lowest was mixed fertilizer (2.98 ton/hectare).

The analysis of variance for all components (Table 52) showed significant differences between block (F=8.43-9.91**) and provenances (main effect) (F=5.17-6.06**). The mean comparison by LSD separated provenances into 3 groups. The highest biomass was found in provenance from Muang, Kanchanaburi and in chemical fertilizer type. This is similar in all components.

Table 51 Biomass of provenance x fertilizer trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Fertilizers/ Provenances	Biomass (kg)			
	Stem	Leaves	Branches	Total
Control/4	1.69	0.33	0.20	2.31
Control/5	2.91	0.60	0.44	4.32
Control/6	2.75	0.55	0.38	3.98
Control/8	2.26	0.45	0.30	3.22
Control/9	1.55	0.30	0.19	2.15
Chemical/4	2.00	0.40	0.28	2.89
Chemical /5	2.32	0.47	0.32	3.36
Chemical /6	4.02	0.83	0.62	6.05
Chemical /8	3.35	0.69	0.51	5.02
Chemical /9	1.80	0.35	0.22	2.49
Manure/4	2.65	0.53	0.36	3.83
Manure/5	2.83	0.57	0.39	4.07
Manure/6	2.32	0.46	0.30	3.29
Manure/8	2.54	0.52	0.39	3.79
Manure/9	1.18	0.22	0.13	1.55
Mixed/4	2.03	0.40	0.24	2.79
Mixed/5	1.86	0.36	0.23	2.57
Mixed/6	2.82	0.57	0.39	4.09
Mixed/8	2.37	0.47	0.31	3.35
Mixed/9	1.75	0.34	0.22	2.42
Provenances				
4	2.10^{bc}	0.42	0.27	2.96
5	2.47^{ab}	0.50	0.34	3.56
6	2.98^{a}	0.61	0.42	4.36
8	2.65^{ab}	0.54	0.38	3.88
9	1.58^{c}	0.31	0.19	2.16
Fertilizers				
control	2.25	0.45	0.31	3.22
chemical	2.70	0.55	0.39	3.97
manure	2.33	0.47	0.32	3.34
mixed	2.12	0.42	0.27	2.98
Mean	2.35	0.47	0.32	3.38

The mean comparisons as shown in letter are similar for all components due to the same parameters, including DGL and total height at the same age, were used in all allometric equations.

Table 52 Analysis of variance on biomass of provenance x fertilizer trials of Siamese Senna at 36 months old in Lad Krating Plantation, Chachoengsao established in 2006

Components	Sources	DF	SS	MS	F
Stem	Blocks	3	21.53	7.18	9.91^{**}
	Provenances	4	17.55	4.39	6.06^{**}
	Fertilizers	3	2.61	0.87	1.20^{ns}
	Provenances x fertilizers	12	10.61	0.88	1.22^{ns}
	Error	57	41.27	0.72	
Leaves	Blocks	3	0.99	0.33	9.80^{**}
	Provenances	4	0.79	0.20	5.85^{**}
	Fertilizers	3	0.13	0.04	1.28^{ns}
	Provenances x fertilizers	12	0.49	0.04	1.19^{ns}
	Error	57	1.93	0.03	
Branches	Blocks	3	0.61	0.20	8.43^{**}
	Provenances	4	0.50	0.13	5.17^{**}
	Fertilizers	3	0.11	0.04	1.53^{ns}
	Provenances x fertilizers	12	0.33	0.03	1.14^{ns}
	Error	57	1.39	0.02	
Total	Blocks	3	53.31	17.77	9.47^{**}
	Provenances	4	43.29	10.82	5.77^{**}
	Fertilizers	3	7.66	2.55	1.36^{ns}
	Provenances x fertilizers	12	26.82	2.23	1.19^{ns}
	Error	57	106.93	1.88	

^{ns} Non-significant difference

* Significant difference at 0.05 level

** Significant difference at 0.01 level

2.2 Coppicing ability

Due to the analysis method, the results of cutting level on coppicing ability are shown in 3.4.

3. Performance ranking of Siamese Senna provenances

The summation and scoring of growth characteristics for the ranking of the overall best performing provenances is shown in Table 53. Due to data unavailable in specific gravity, coppice number, coppice base diameter, and coppice total height of some provenances. The ranking was done 2 times based on the available data. The 1st ranking excluded specific gravity, coppice number, coppice base diameter, and coppice total height while the 2nd ranking included these parameters. In the 2nd ranking, the score summations of provenances from Muang, Kanchanburi and Muang Songkhla were divided by 7 while the other provenances were divided by 11. This is to eliminate the effect of unequal parameters of all provenances. Although this method might not be the best way to eliminate, the both ranking results showed the similar rank for the 3 best ranking provenances and 3 worst ranking provenances. The best 3 ranking provenances were Potaram, Ratchaburi (seedlot 2002), Muang, Kanchanaburi, and Muaklek, Saraburi. The worst 3 ranking provenances were Muang, Songkhla, Ngao, Lampang, and Potaram, Ratchaburi (seedlot 2000). This could be the result of low soil moisture content in the provenance trials. Although the average rainfall during study period was high (1,437 mm per year) but the trees were planted with 4x4 m spacing and the crown development in the first 3 years were not fully covered the area. So there were a lot of open spaces allowing the evaporation of soil. The provenance from Potaram, Ratchaburi (seedlot 2002) had the lowest rainfall compared to other provenances (Table 1) so this provenance could adapt to the dry area better than the others. For the Muang (Kanchanaburi) provenance, the altitude was 40 m above sea level which was very close to altitude at Lad Krating plantation (45 m above sea level). Similar result was reported by Mwase *et al.*(2010) in *Uapaca Kirkiana* which superior provenance performed in the provenance trials was attributed to similarity of the climatic factors, especially rainfall and elevation between seed source and experimental site.

Table 53 The scoring of each characteristic and ranking of provenance trials of Siamese Senna at Lad Krating Plantation, Chachoengsao established in 2006

Provenances	Score													Composite ranking	
	Survival rate at 1 month old	Survival rate at 36 months old	DGL	Ht	RDGL	RHt	Biomass	Specifi gravity	Coppice No.	Coppice D0	Coppice Ht	Total[1]	Total[2]	Ranking[1]	Ranking[2]
1	6	2	9	8	2	3	9	6	5	6	6	39	5.64	8	8
2	7	6	4	6	2	3	5	1	3	1	1	33	3.55	6	4
3	3	6	5	5	2	2	6	4	2	5	5	29	4.09	5	5
4	5	1	7	7	1	2	4	1	4	7	7	27	4.18	4	6
5	2	4	3	3	2	4	3	3	4	3	2	21	3.00	3	3
6	4	8	2	2	1	1	2	-	-	-	-	20	2.86	2	1
7	8	5	8	4	2	2	7	5	6	1	4	36	4.73	7	7
8	1	3	1	1	2	3	1	6	7	4	3	12	2.91	1	2
9	9	9	6	9	2	3	8	-	-	-	-	46	6.57	9	9

Remarks: DGL=diameter at ground level, Ht=total height, RDGL=relative growth rate of DGL, RHt=relative growth rate of height, D0=Diameter at coppice base

[1]Exclude specific gravity, coppice no., coppice D0 and coppice height

[2]Include specific gravity, coppice no., coppice D0 and coppice height

CONCLUSION AND RECOMMENDATIONS

Conclusion

Provenance variation of Siamese Senna on seed morphological characteristics, growth performances, biomass, wood specific gravity, and coppicing ability in provenance trials at Lad Krating plantation, Chachoengsao established in 2006 are concluded, as follows:

Average of width, length, thickness and 1000-seed weight were 5.75 mm, 7.56 mm, 0.78 mm, and 25 g, respectively. Average seed width varied from 5.50 mm (Takbai, Narathiwat provenance) to 6.09 mm (Muaklek, Saraburi provenance). The average seed length ranged from 7.22 mm (Potaram, Ratchaburi-seedlot 2000 provenance) to 8.28 mm (Muang, Songkhla provenance). The average seed thickness was varied from 0.55 mm (Muang, Kanchanaburi provenance) to 0.96 mm (Muang, Songkhla provenance). The average 1000-seeds weight varied from 22.5 g (Potaram, Ratchaburi-seedlot 2002 provenance) to 27.6 g (Muang, Songkhla provenance). Ananlysis of variance showed statistically highly significant differences in all seed morpometric characteristics. The broad sense heritability of width, length, thickness and 1000-seed weight were 50%, 69%, 83%, and 83%, respectively.

Average survival percentage drop gradually from ages 2, 3, 4, 5, 6, 12, 24, to 36 months old with 90.44%, 89.89%, 88%, 87.11%, 86.11%, 81.89%, 81.89% to 8.22% respectively. Takbai, Narathiwat was the top surviving provenance at 36 months old while Muang, Songkhla was the least surviving provenance. Survival percentages had statistically significant differences during 1 to 6 months old. During 12 to 36 months old, survival percentages were not statistically significantly different.

Average DGL increased from 0.50, 0.58, 0.81, 1.06, 1.27, 1.35, 2.71, 3.21, to 4.46 cm in sequence at 1, 2, 3, 4, 5, 6, 12, 24, 36 months after planting. The lowest DGL was recorded for Ngao, Lampang provenance (3.76 cm) while the highest DGL was recorded for Potaram, Ratchaburi (seedlot 2002) provenance (5.10 cm) at 36 months old. The variations of average DGL among provenances were statistically significant in all measuring ages except at 5 months old. The broad sense heritability at different months ranged from 25-57%.

Average total height increased from 34.56, 38.80, 50.44, 65.69, 79.49, 82.07, 155.02, 317.76 to 458.86 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, 36 months old, respectively. The least performing provenance was from Ngao, Lampang provenance with the total height of 336.61 cm while Potaram, Ratchaburi-seedlot 2002 was the best performing with the total height of 521.79 cm at 36 months old. There were statistically highly significant differences among provenances in all measuring ages. The broad sense heritability at different months ranged from 43.62% to 85.16%.

Average RDGL during 1-12, 12-24, 24-36, and 1-36 months old were 0.15, 0.02, 0.03, and 0.06 cm/cm/month, respectively. Provenance from Takbai, Narathiwat; Muang, Kanchanaburi performed the best RDGL with 0.07 cm/cm/month during 1-36 months old. The other provenances performed the similar RDGL at 0.06 cm/cm/month. The variation of average RDGL was statistically significant only during 12-24 months old.

Average relative growth rate of height during 1-12, 12-24, 24-36, and 1-36 months old were 0.14, 0.06, 0.03, and 0.07 cm/cm/month, respectively. The best performing provenance was from Muang, Kanchanaburi with relative growth rate of height of 0.09 cm/cm/month while the least performing provenance was Muaklek, Saraburi with relative growth rate of height of 0.06 cm/cm/month. The variations of average relative growth rate of height among provenances were statistically highly significant during 1-12, 12-24, and 1-36 months old.

Average biomass at 24 months old of stem, leaves, branches, and total were 1.77, 1.06, 0.83, and 3.63 ton/hectare, respectively. The best performing provenance in all components was Potaram, Ratchaburi (seedlot 2002) with biomass of 2.64, 1.59, 1.22 and 5.48 ton/hectare for stem, leaves, branches, and total, respectively. The least performing provenance in all components was Ngao, Lampang with biomass of 1.05, 0.63, 0.50, and 2.11 ton/hectare for stem, leaves, branches, and total, respectively. Analysis of variance showed statically highly significant differences among provenances in all components.

Average biomass at 36 months old of stem, leaves, branches, and total were 3.69, 0.77, 0.58, and 5.59 ton/hectare, respectively. The best performing provenance in all components was Potaram, Ratchaburi (seedlot 2002) with biomass of 5.15, 1.09, 0.88 and 8.06 ton/hectare for stem, leaves, branches, and total, respectively. The least performing provenance in all components was Ngao, Lampang with biomass of 2.14, 0.43, 0.29, and 3.04 ton/hectare for stem, leaves, branches, and total, respectively. Analysis of variance showed statically highly significant differences among provenances in all components.

Average wood specific gravity was 0.56. The best performing provenance was Takbai, Narathiwat and Muang, Tak with specific gravity of 0.58 while Ngao, Lampang and Potaram, Ratchaburi (seedlot 2002) were the least performing provenances with specific gravity of 0.54. The highest specific gravity was found at 0 and 0.5 m height level at 0.57 while the lowest was found at 2 m height level at 0.53. The variation of average wood specific gravity was statistically highly significant between provenances and between levels.

Coppicing ability was studied in 3 characteristics including number of coppice, diameter at base level of coppice (DBL), and total height of coppice. Average number of coppice was 8.06, 8.82, 8.36, 8.74, 6.22, and 5.88 coppices at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing provenance was Takbai, Narathiwat with 7.06 coppices while the least performing provenance was Potaram, Ratchaburi (seedlot 2002) with 5.27 coppices. The variation of average number of coppice was statistically highly significant among provenances only at 1 month old. Average DBL of coppice was 0.81, 1.05, 1.09, 1.17, 1.80, and 2 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing provenance was Muang, Tak and Potaram, Ratchaburi (seedlot 2000) with DBL of coppice of 2.26 cm while the least performing provenance was Takbai, Narathiwat with DBL of coppice of 1.39 cm. The variations of average number of coppice were statistically significant among provenances at 3 and 4 months old. Average total height of coppice increased from 69.93, 106.40, 115.95, 124.80, 173.07 to 190.94 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing provenance was Muang, Tak with total height of coppice of 219.83 cm while the least performing provenance was Takbai, Narathiwat with total height of coppice of 147.08 cm. The variation of average number of coppice was statistically significant among provenances at 1 and 6 months old.

The study on molecular genetics was carried out at Forest Genetic Conservation and Biology Research Division, Department of National Parks, Wildlife and Plant Conservation. The suitable DNA extraction protocol for Siamese Senna was sorbital buffer protocol with some modification. The results of ISSR analysis were concluded, as follows:

The percentage of polymorphic bands among different provenance ranged from 32.08% to 71.7%. At the species level, 53 polymorphic loci were detected. The percentage of polymorphic bands (PPB) was 90.57%, Genetic diversity (He) was 0.262, effective number of allele (Ae) was 1.9057, and Shannon's information index (I) was 0.4033. Genetic differentiation (Gst) detected by Nei's genetic diversity analysis was 0.2852. The average number of individuals exchanged between populations per generation (Nm) was 1.2503

Management practices had been studied in 2 aspects including effect of fertilizer types on growth and production, and effect of cutting level on coppicing ability. The fertilizer was studied in provenance x fertilizer trials while the cutting level was studied in the provenance trials. The results are concluded as follows.

Average survival percentages from ages 2, 3, 4, 5, 6, 12, 24, to 36 months old were 93.06%, 92.92%, 90%, 90.14%, 87.08%, 80.14%, 79.17% to 79.72% respectively. Chemical fertilizer was the top surviving fertilizer type at 36 months old while mixed fertilizer was the least surviving fertilizer type. Survival percentages had statistically highly significant differences only at 1 month old.

Average DGL increased from 0.40, 0.43, 0.56, 0.70, 0.83, 0.87, 2.13, 2.52, to 3.78 cm in sequence at 1, 2, 3, 4, 5, 6, 12, 24, 36 months after planting. The lowest DGL was recorded for manure fertilizer (3.71 cm) while the highest DGL was recorded for chemical fertilizer (3.84 cm) at 36 months old. The variations of average DGL among fertilizer types were not statistically significant in all measuring ages.

Average total height increased from 32.24, 34.51, 40.03, 45.99, 54.90, 57.17, 119.03, 254.09 to 381.63 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, 36 months old, respectively. The best performing fertilizer type was chemical fertilizer with the total height of 401.69 cm while mixed fertilizer was the least performing with the total height of 365.35 cm at 36 months old. There was statistically highly significant difference among provenances only at 2 months old.

Average RDGL during 1-12, 12-24, 24-36, and 1-36 months old were 0.15, 0.01, 0.03, and 0.06 cm/cm/month, respectively. All fertilizer types performed the same RDGL with 0.06 cm/cm/month during 1-36 months old. The variations of average RDGL among fertilizer types were not statistically significant in all growing stages.

Average relative growth rate of height during 1-12, 12-24, 24-36, and 1-36 months old were 0.12, 0.06, 0.03, and 0.07 cm/cm/month, respectively. All fertilizer types performed the same relative growth rate of height with 0.07 cm/cm/month. The variations of average relative growth rate of height among fertilizer types were not statistically significant in all growing stages.

Average biomass at 24 months old of stem, leaves, branches, and total were 0.94, 0.57, 0.46, and 1.93 ton/hectare, respectively. The best performing fertilizer type in all components was chemical fertilizer with biomass of 1.01, 0.62, 0.50 and 2.09 ton/hectare for stem, leaves, branches, and total, respectively. The least performing fertilizer type in all components was mixed fertilizer with biomass of 0.94, 0.57, 0.46, and 1.93 ton/hectare for stem, leaves, branches, and total, respectively. Analysis of variance showed no statically significant differences among fertilizer types in all components.

Average biomass at 36 months old of stem, leaves, branches, and total were 2.35, 0.47, 0.32, and 3.38 ton/hectare, respectively. The best performing fertilizer type in all components was chemical fertilizer with biomass of 2.70, 0.55, 0.39 and 3.97 ton/hectare for stem, leaves, branches, and total, respectively. The least performing fertilizer type in all components was mixed fertilizer with biomass of 2.12, 0.42, 0.27, and 2.98 ton/hectare for stem, leaves, branches, and total, respectively. Analysis of variance showed no statically significant differences among fertilizer types in all components.

Average number of coppice was 8.06, 8.82, 8.36, 8.74, 6.22, and 5.88 coppices at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing cutting level was 1.30 m with 6.56 coppices while the least performing cutting level was 0 m with 5.32 coppices. The variations of average number of coppice were statistically significant among levels at 5 and 6 months old. Average DBL of coppice was 0.81, 1.05, 1.09, 1.17, 1.80, and 2 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing cutting level was 0 m with DBL of coppice of 2.20 cm while the least performing cutting level was 1.30 m with DBL of coppice of 1.76 cm. The variations of average number of coppice were statistically highly significant among cutting levels at 2, 3, 4, 5, and 6 months old. Average total height of coppice increased from 69.93, 106.40, 115.95, 124.80, 173.07 to 190.94 cm at ages 1, 2, 3, 4, 5, 6, 12, 24, and 36 months old, respectively. The best performing cutting level was 0 m with total height of coppice of 223.67 cm while the least performing cutting level was 1.30 with total height of coppice of 151.53 cm. The variations of total height of coppice were statistically highly significant among cutting levels at 2, 3, 4, 5, and 6 months old.

The result of performances ranking of Siamese Senna provenances showed that the best 3 ranking provenances were Potaram, Ratchaburi (seedlot 2002), Muang, Kanchanaburi, and Muaklek, Saraburi. The worst 3 ranking provenances were Muang, Songkhla, Ngao, Lampang, and Potaram, Ratchaburi (seedlot 2000).

Recommendations

The present study on genetic variations and management practices of Siamese Senna can suggest the recommendations, as follows:

1. The provenances from Potaram, Ratchaburi (seedlot 2002); Muang, Kanchanaburi; Muaklek, Saraburi; Takbai, Narathiwat; and Chaibadal, Lopburi were recommended for planting in Chachoengsao and Eastern provinces.

2. Based on genetic distance results, the recommended provenances were found in all distinct groups suggest selection of elite trees over ranges for future breeding program.

3. The suitable fertilizer for 36 months old Siamese Senna in this study was chemical fertilizer (NPK, 15-15-15). It is suggested to study in details on NPK ratio, rate, and frequency of application.

4. It is recommended to harvest fuelwood at ground level. However, in the area of wood scarcity pollarding at 2 m level is suggested.

5. Though Siamese Senna is a potential source of fuelwood, it is recommended to grow mixed MPTS and create the cutting rotation in any given area to avoid fuelwood shortage as well as pests and diseases.

6. The differences between seedlots of Potharam, Ratchaburi suggest that seed collection should be done in the good seed year to avoid the narrow genetic bases.

7. The natural distribution from literature review did not include Cambodia and Laos which might due to the unavailable of taxonomy research publications. As this species is of prime important to energy, food security and medicine, it is

recommended to start the collaboration among ASEAN countries and create the international provenance trials to serve the future needs in this region.

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