Effects of coppicing and seedling options on financial evaluation of teak (*Tectona grandis* L.) farm plantation management in Thailand

Iwao Noda[1)2)]*, Woraphun Himmapan[3)]

[1)] Forestry Division, Japan International Research Center for Agricultural Sciences, 1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan.
[2)] Present address: Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan.
[3)] Silvicultural Research Division, Forest Research and Development Bureau, Royal Forest Department, 61 Phaholyothin Rd., Chatuchak, Bangkok 10900, Thailand.
* *Corresponding author; E-mail: noda12@affrc.go.jp*

Abstract

Teak (*Tectona grandis* L.) plantation management has been shown to be a profitable venture in Thailand. However, reduction of the initial investment cost is an important challenge for farmers to be able to conduct sustainable management. In particular, tree planting is the most burdensome part. Teak plantations are considered to be regenerable by coppicing. Therefore, this study established discounted cash flow models for producing teak timber with 15-year or 20-year rotation cycles, and evaluated the profitability of coppicing for reforestation with genetically improved seedlings using incremental net present value (NPV). The results showed that the use of coppicing reduced reforestation costs by nearly 60% compared with seedlings. The incremental NPV was markedly affected by the productivity of coppices and genetic gain in volume production of seedlings.

Keywords: *Tectona grandis*, Coppicing, Genetic improvement, Reforestation, Discounted cash flow

Introduction

Teak (*Tectona grandis* L.) is the premier cultivated high quality cabinet wood of the world and the decline of the natural resources and prudent management objectives (White 1991). Natural teak forests grow in only four countries in the world: India, Lao PDR, Myanmar and Thailand, declined in area by 1.3% between 1992 and 2010, Myanmar is the only country that currently produces quality teak from natural teak forests, and teak planting serves local communities as savings account and the long run helps smallholders improve their livelihoods (Kollert and Cherubini 2010).

In Thailand, the creation of teak plantations on private land was initiated after an afforestation subsidy project in 1994, and most cases involve small-scale farmers (Royal Forest Department 2002; Yokota et al. 2009). The management of teak plantations has been shown to be a profitable activity, an intensive operating model for large-scale business has been proposed (Phothitai 1993). According to a previous study, teak is more profitable than *Eucalyptus camaldulensis* Dehn in all of the following three types of forestation: intensive industrial plantations in Northeast Thailand, relatively extensive plantations in communities, and agroforestry or crop cultivation in forests by farmers (Niskanen 1998). Noda et al.(2004) pointed out for small-scale farmers that: 1) although teak plantation management by farmers in Northeast Thailand was more profitable than that of Eucalyptus plantations due to stably higher log price and higher benefit/cost ratio, the initial investment including expenses for planting is burdensome; 2) no income is obtained for 10 or 20 years before teak trees grow to a marketable size; and 3) it is necessary to discuss methods for the efficient utilization of land by cultivating agricultural crops during this period. A study conducted by Noda et al. (2012b) in Northeast Thailand suggested that combined farm management based on a mixture of agriculture and forestry is expected to reduce initial costs, and that rice production can be the primary element to increase profitability as a land utilization strategy. Teak plantations are believed to be restorable by coppicing (Thaiutsa et al. 2001; Bailey and Harjanto 2005; Himmapan and Noda 2012). Using a discounted cash flow model, a profit analysis of coppicing in *Eucalyptus globulus* plantations in Australia for pulp production was conducted, and the results suggested that coppicing may reduce the initial investment required (Whittock et al. 2004). Himmapan and Noda (2012) showed a preliminary result of monitoring teak plantations up to 22 months old in Kanchanaburi, Thailand, but coppice sprouts from stump of final cutting were better than those from thinning and seedlings, the coppice might be expected as low cost reforestation method and also to reduce the burden of weed control cost. Thus, coppicing in teak timber management has been expected to reduce costs, but no previous studies have included comparative financial evaluations of coppicing for teak timber management for Thai farmers except Noda and Himmapan (2012a). On teak timber production managements for farmers in Thailand, Noda and Himmapan (2012a) made discounted cash flow models and evaluated the profitability of coppicing concerning reforestation with genetically improve seedlings. Noda and Himmapan (2012a), however, studied a limited case of plant spacing 4 m × 4 m in a 15-year rotation cycle. In the present study, a financial evaluation of coppicing in plantations was conducted using the discounted cash flow models in the simulation of teak plantation managements with standard silvicultural alternatives for Thai farmers, thus, plant spacing of 4 m × 4 m and 3 m × 3 m, and short rotation periods of 15 years and 20 years.

Materials and methods

The study area was the northeast region in Thailand, which borders Cambodia and Laos. Two-thirds of the region is covered by the alluvial plateau of the Korat basin with an elevation 100–300 m, and the region is surrounded by mountain ranges to the south, west and northeast (Wongwiwatchai and Paisancharoen 2002). The climate of the region has two major seasons of the southwest monsoon and the northeast monsoon. The southwest monsoon is characterized by the wet season with maximum monthly rainfall of about 300 mm, and the northeast monsoon is mostly dry with very occasional light showers. The annual rainfall and the monthly mean temperature range from 1,100 mm/year and 22°C to 1,800 mm/year and 29°C (Phien et al. 1980). Most of the soils in Northeast Thailand are derived from sandstone, shale, or siltstone (Ragland and Boopuckdee 1988).

In our study, we investigated different silvicultural alternatives, with rotation periods of 15 years and 20 years, and plant spacing of 4 m × 4 m and 3 m × 3 m, as part of the standard management plan for teak plantations (Table 1) developed by the Royal Forest Department for farms in Northeast Thailand.

Cash flow models

Thirty-year cash flow models were created to represent the plantation system (Table 1) developed by the Royal Forest Department for farms in Northeast Thailand, in which trees were planted at intervals of 4 m × 4 m and 3 m × 3 m and logged in 15 years (two rotations in 30 years). In addition, 40-year cash flow models were created to investigate a plantation system in which trees were planted at intervals of 4 m × 4 m and 3 m × 3 m and logged in 20 years (two rotations in 40 years).

As in the previous study (Whittock et al. 2004), two analysis models were created for managing teak plantations from seedlings in the first rotation (1R), and from coppices (coppicing model) or seedlings (seedling model) in the second rotation (2R) (Table 2). The model allows changes in productivity due to coppicing or genetic improvement to be investigated in terms of financial evaluation (Whittock et al. 2004). Because genetic improvement of the seedlings used in the 1R may increase the yield in the 2R, a *VGAIN* (representing the effect of the genetic improvement of seedlings) was adopted as a variable.

The management plan shown in Table 1 was implemented in the 1R, and, in the 2R, modifications were added to the plantation procedures conducted in the first year, depending on the model (Table 3). Although the coppicing model does not involve planting trees, seedlings for supplementary planting were prepared on the assumption of a 10% coppice mortality rate, and the workload required for "alignment and staking" was determined to be 0.5 man-day. Regarding the seedling model, the workload required to perform preparation for re-afforestation, including removal of the roots of logged trees and clearance, was assumed to be heavier. The "percentage cost gain in land preparation" [*r*] was adopted to adjust the workload for "land preparation" and "slash and burn", the base value was determined by reference to *Eucalyptus globulus* plantations in Whittock et al. (2004) (Table 3).

The percentage increase in the volume of trees to the volume of seedlings prior to genetic improvement in the 1R was defined as the coppicing productivity (*CPROD*), and the percentage effect of genetic improvement of seedlings on the increase in the volume production was defined as the *VGAIN*. Variables were the price of logs at the time of logging (*LogPrice*), volumes of logged trees in the coppicing (*Yc*) and seedling (*Ys*) models, and discount rate (*d*) (Table 4):

$Yc = Yn \times CPROD / 100$ ……………………………...(1)

$Ys = Yn \times (1 + VGAIN / 100)$ …………………………(2)

where *Yn* represents the volume of seedlings (not genetically improved) logged in Table 1 (yield log volume).

In the financial evaluation, criteria are calculated using discounted cash flow analysis techniques. The criteria used in the study were the net present value (NPV) (Price 1989; Davis et al. 2005) and incremental NPV (Irvin 1978) as increments in the yield in the coppicing model:

$NPV = \Sigma (Rt - Ct) / (1 + d/100)^t$……………….………(3)

where *Rt*, *Ct* are revenue and cost in year *t*, and *d* is the discount rate in percentage figures. For application of the NPV, we should select the highest NPV from a group of compatible investments (Price 1989). Incremental NPV was used to compare the two mutually exclusive options (Dasgupta and Pearce 1972). A positive incremental NPV indicated that the NPV of coppicing exceeded the NPV of seedlings in the 2R, whilst a negative incremental NPV indicated that the NPV of a seedling crop exceeded the NPV of a coppiced crop in the 2R (Whittock et al. 2004). The incremental NPV was calculated by subtracting the NPV in the seedling model from that in the coppicing model. The models were created using MS-Excel.

Simulation analysis

The responses of outputs to input variables were examined using Oracle Crystal Ball 11 (EPM Information Development Team 2013) to use probability distributions of variables and conduct Monte Carlo simulations with 100,000 iterations for the following steps. First, the effect of coppicing on reducing the initial investment was examined from the viewpoint of cash balance. We, thus, calculated percentage change of economic balances in the first year of the 2R between the coppicing and the seedling models as mean ± standard deviation of percentage changes simulated with the assumptions of variables shown as Tables 4. Second, the effects of the combination of *CPROD* and *VGAIN* on the incremental NPV were analyzed using the decision table tool (EPM Information Development Team 2013). We evaluated responses of incremental NPVs for the combination of *CPROD* and *VGAIN* by discount rate of 10% and 7%, respectively, to additionally compare effects of discount rate. Third, the sensitivity of variables corresponding to incremental NPVs was analyzed under the assumptions (Table 4), using rank correlation coefficients, to identify variables closely related to the effect of coppicing on increasing profits.

The occurrence probabilities of all variables with the exception of the percentage cost gain (*r*) were defined by the triangular distribution, determined by the base, minimum, and maximum values (Table 4). The base, minimum and maximum values of all variables were set with reference to previous studies. The *CPROD* and [*d*] were allowed to vary according to a triangular distribution with maximum and minimum values ±20% of the base value, and the *LogPrice* was ±10% of the base. The *VGAIN* was fitted with a triangular distribution ranging from 0 to 40% with the likeliest value 20%. The [*r*] was allowed to vary from 0% to 100% with a uniform distribution. The costs of labor, seedlings, and fertilizers were 180 baht/man-day, 5 baht/tree, and 10 baht/kg, respectively (Royal Forest Department 2006).

Results and Discussion

Effects of coppicing on reducing the initial investment

The mean percentage changes of economic balances of the coppicing model in the first year of the 2R for the seedling model were calculated as improved by 56.9 ± 3.3% (4 m × 4 m) and 56.8 ± 2.9% (3 m × 3 m). These results were not different between rotations of the 15-year and 20-year, since the cash flow in the first year is not affected by rotation period. The choice of coppicing reduced reforestation costs by nearly 60% compared with the seedling one, where these results were based only on regeneration by coppicing or seedlings in the 2R, not affected by productivity variables.

Effects of the combination of *CPROD* and *VGAIN*

The relationship between the incremental NPV and the combination of the *CPROD* and *VGAIN* is shown on Fig. 1 by rotation and spacing. The results from different discount rates are overlaid together.

1) Discount rate 10%

When the discount rate was 10%, the *CPROD* was 70% to 130% and the *VGAIN* was -10% to 40%, and the change in the incremental NPV was 5,096 (-2,557 to 2,539) baht/rai (4 m × 4 m) and 5,026 (-2,434 to 2,592) baht/rai (3 m × 3 m) in the 15-year rotation, and 4,521 (-2,451 to 2,070) baht/rai (4 m × 4 m) and 4,167 (-2,177 to 1,990) baht/rai (3 m × 3 m) in the 20-year rotation.

If the productivity of the coppiced crop was equivalent to the 1R seedling crop (*CPROD* was 100%), then genetic gain (*VGAIN*) would be required at a minimum of ~15% (4 m × 4 m) and ~16% (3 m × 3 m) in the 15-year rotation, and ~10% (4 m × 4 m) and ~13% (3 m × 3 m) in the 20-year rotation for a seedling crop to have an NPV higher than the coppiced crop (incremental NPV < 0) (Fig. 1). If *CPROD* was 110%, then the thresholds of VGAIN would be increased to ~25% (4 m × 4 m) and ~26% (3 m × 3 m) in the 15-year rotation, and ~21% (4 m × 4 m) and ~23% (3 m × 3 m) in the 20-year rotation for a seedling crop to have a negative incremental NPV.

With no genetic improvement effect on seedlings (*VGAIN* was 0%), the change in productivity of the coppiced crop to the seedling crop (*CPROD*) would need to be at least ~85% (4 m × 4 m) and ~84% (3 m × 3 m) in the 15-year rotation, and ~90% (4 m × 4 m) and ~88% (3 m × 3 m) in the 20-year rotation for the coppice crop to have a higher NPV than the seedling crop (incremental NPV > 0).

If the productivity of the coppiced crop was equivalent to the seedling crop (*CPROD* was 100%) with no genetic improvement in the seedlings (*VGAIN* was 0%), then the NPV of the coppicing model was higher compared with the seedling model by 12.9 ± 2.5% (4 m × 4 m) and 21.1 ± 4.7% (3 m × 3 m) in the 15-year rotation, and 3.3 ± 0.5% (4 m × 4 m) and 5.1 ± 0.7% (3 m × 3 m) in the 20-year rotation.

2) Discount rate 7%

When the discount rate was 7%, the *CPROD* was 70 to 130% and the *VGAIN* was -10 to 40%, and the change in the incremental NPV was 10,823 (-5,820 to 5,003) baht/rai (4 m × 4 m) and 10,527 (-5,509 to 5,018) baht/rai (3 m × 3 m) in the 15-year rotation, and 12,084 (-6,929 to 5,155) baht/rai (4 m × 4 m) and 11,200 (-6,279 to 4,921) baht/rai (3 m × 3 m) in the 20-year rotation. The lower the discount rate became, the more the change in volume production by the *CPROD* or *VGAIN* had elastic effects on the profits.

If the productivity of the coppiced crop was equivalent to the 1R seedling crop (*CPROD* was 100%), then genetic gain (*VGAIN*) would need to be at least ~11% (4 m × 4 m) and ~13% (3 m × 3 m) in the 15-year rotation, and ~7% (4 m × 4 m) and ~8% (3 m × 3 m) in the 20-year rotation for a seedling crop to have an NPV higher than the coppiced crop (incremental NPV < 0) (Fig. 1). If *CPROD* was 110%, then the thresholds of *VGAIN* would be required to be up to ~21% (4 m × 4 m) and ~23% (3 m × 3 m) in the 15-year rotation, and ~17% (4 m × 4 m) and ~18% (3 m × 3 m) in the 20-year rotation for a seedling crop to have a negative incremental NPV.

With no genetic improvement effect on seedlings (*VGAIN* was 0%), the change in productivity of the coppice crop to the seedling crop (*CPROD*) would need to be at least ~90% (4 m × 4 m) and ~87% (3 m × 3 m) in the 15-year rotation, and ~94% (4 m × 4 m) and ~92% (3 m × 3 m) in the 20-year rotation for the coppiced crop to have a higher NPV than the seedling crop (incremental NPV > 0).

If the productivity of the coppiced crop was the same as the seedling crop (*CPROD* was 100%) with no genetic improvement in the seedlings (*VGAIN* was 0%), then the NPV of the coppicing model was higher compared with the seedling model by 8.1 ± 1.3% (4 m × 4 m) and 11.1 ± 1.8% (3 m × 3 m) in the 15-year rotation, and 2.6 ± 0.4% (4 m × 4 m) and 3.5 ± 0.5% (3 m × 3 m) in the 20-year rotation. The lower the discount rate became 7% from 10%, the less the coppicing model had gain in the NPV on the seedling model.

Sensitivity of variables corresponding to incremental NPVs

CPROD and *VGAIN* correlated with the incremental NPV (Table 5). For the NPV, the discount rate (d) was strongly and negatively correlated, and log price at final logging (*LogPrice15* in the 15-year rotation; *LogPrice20* in the 20-year rotation) was moderately correlated. The "percentage cost gain in land preparation" [r] was not correlated with either. These results suggested that *CPROD* and *VGAIN* are important in the selection of methods for coppicing or planting in the 2R, and that it is necessary to increase the unit log price by improving the log quality at the final time of logging to effectively increase profits.

It is believed that in areas where coppices can grow into mature trees, coppicing is a more effective reforestation method compared with planting seedlings, which grow relatively slowly (Harcombe and Marks 1983; Ohkubo 1992). Himmapan and Noda (2012) and Kwame et al. (2014) studied growth performances of coppiced trees, but only until 1 or 2 years after coppicing. In 3-, 8-, and 13-year-old teak plantations in Java, the mean height and diameter at breast-height of coppiced trees were larger than those of planted trees (Bailey and Harjanto 2005). This means that the *CPROD* is almost always 100% or higher. According to a study on teak breeding in Thailand, the volume of seedlings cultivated in a seed orchard tended to be 5–12% larger (Wellendorf and Kaosa-ard 1988). Kjaer and Suangtho (1997) estimated that seedlings from classified seed stands are expected to have at least 8% higher production value than seedlings from unclassified seeds (this increased production value originated from both improved production volume and better stem form) (Kaosa-ard et al. 1998). Therefore, *VGAIN* is estimated to be approximately 10% if genetically selected seedlings are not used in the 1R and adopted in the 2R, and 0% otherwise. In this case, if the *CPROD* is 100 or 110%, which is lower than the threshold of the *VGAIN* (about 15 or 25%) calculated based on the results of the present study, the effect of coppicing on increasing profitability is supported. However, as the results of previous study show (Whittock et al. 2004), when the actual *VGAIN* is close to the above-mentioned threshold, or the NPV of the coppicing model is similar to that of the seedling model, it is necessary to select a method with a lower risk that helps promote the growth of trees more effectively.

Conclusion

The present study examined the effects of changes in productivity of a coppiced crop and the genetic gain in volume production of seedlings on a financial evaluation to compare coppiced and seedling options for teak plantations with 15- and 20-year rotations, including the efficacy of coppicing with a focus on differences in the regeneration method in the 2R. The results suggested that coppicing reduces the initial investment, and its profitability may be greater than that of planting seedlings. As future challenges, it will be necessary to examine the ranges of variables used for the analyses and the validity of the models.

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Table 1. Management plans for planted teak forest plantations

Activity	Unit	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rotation period 15 years; plant spacing 4 m × 4 m																
Survey	man-day	0.5														
Land preparation	man-day	4														
Slash and burn	man-day	4														
Survey road	man-day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man-day	1														
Alignment and Staking	man-day	2														
Planting and seedling transportation	man-day	3														
Weeding	man-day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2
Fertilizing	man-day	0.5	0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man-day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man-day							1	1	1	1		1	1	1	1
Tending cutting 50%	man-day					5										
Logging	man-day										7					7
Number of seedlings	tree	120														
Amount of fertilizer	kg	50	50	50			50	50				100	100			
Yield log volume	m^3	0	0	0	0	3	0	0	0	0	5	0	0	0	0	9
Log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000
Rotation period 15 years; plant spacing 3 m × 3 m																
Activity	Unit	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey	man-day	0.5														
Land preparation	man-day	4														
Slash and burn	man-day	4														
Survey road	man-day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man-day	1														
Alignment and Staking	man-day	2														
Planting and seedling transportation	man-day	3														
Weeding	man-day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2
Fertilizing	man-day	0.5	0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man-day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man-day							1	1	1	1		1	1	1	1
Tending cutting 50%	man-day					5										
Logging	man-day										7					7
Number of seedlings	tree	200														
Amount of fertilizer	kg	75	75	75			75	75				75	75			
Yield log volume	m^3	0	0	0	0	4	0	0	0	0	5	0	0	0	0	8
Log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000

The above are shown as value per rai. 1 rai = 0.16 ha. Source: Royal Forest Department (2006).

Table 1. Management plans for planted teak forest plantations (cont'd)

Rotation period 20 years; plant spacing 4 m × 4 m																					
Activity	Unit	Year																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Survey	man-day	0.5																			
Land preparation	man-day	4																			
Slash and burn	man-day	4																			
Survey road	man-day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man-day	1																			
Alignment and staking	man-day	2																			
Planting and seedling transportation	man-day	3																			
Weeding	man-day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2	6	2	2	2	2
Fertilizing	man-day	0.5	0.5	0.5				0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man-day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man-day							1	1	1	1		1	1	1	1		1	1	1	1
Tending cutting 50%	man-day					5															
Logging	man-day										7					7					7
Number of seedlings	tree	120																			
Amount of fertilizer	kg	50	50	50			50	50				100	100				100	100			
Yield log volume	m^3	0	0	0	0	3	0	0	0	0	5	0	0	0	0	5.5	0	0	0	0	12
Log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000	0	0	0	0	7,000
Rotation period 20 years; plant spacing 3 m × 3 m																					
Activity	Unit	Year																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Survey	man-day	0.5																			
Land preparation	man-day	4																			
Slash and burn	man-day	4																			
Survey road	man-day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man-day	1																			
Alignment and staking	man-day	2																			
Planting and seedling transportation	man-day	3																			
Weeding	man-day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2	6	2	2	2	2
Fertilizing	man-day	0.5	0.5	0.5				0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man-day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man-day							1	1	1	1		1	1	1	1		1	1	1	1
Tending cutting 50%	man-day					5															
Logging	man-day										7					7					7
Number of seedlings	tree	200																			
Amount of fertilizer	kg	75	75	75			75	75				75	75				75	75			
Yield log volume	m^3	0	0	0	0	2.5	0	0	0	0	4.5	0	0	0	0	5	0	0	0	0	11.5
Log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000	0	0	0	0	7,000

Table 2. The formation used to evaluate the incremental NPV of seedlings and coppice crops

Case	The first rotation (1R)	The second rotation (2R)
Case 1: Seedling Model	Plantation from seedlings	Plantation from genetically improved seedlings
Case 2: Coppicing Model	Plantation from seedlings	Plantation from coppices

NPV: net present value.

Table 3. Assumed changes for activities of the 1st year in first rotation (1R), second rotation seedling (2R seedling) and second rotation coppice (2R coppice)

Activity		1R	2R seedling	2R coppice
Land preparation	man-day	4	4 ・ (1 + *r* /100)	1
Slash and burn	man-day	4	4 ・ (1 + *r* /100)	1
Alignment and Staking	man-day	2	2	0.5
Planting and seedling transportation	man-day	3	3	0
Number of seedlings	tree	*n* *1	*n*	*n* × 10/100

*1: The *n* is number of seedlings on Table 1.

Table 4. Variables used in the models and their assumptions

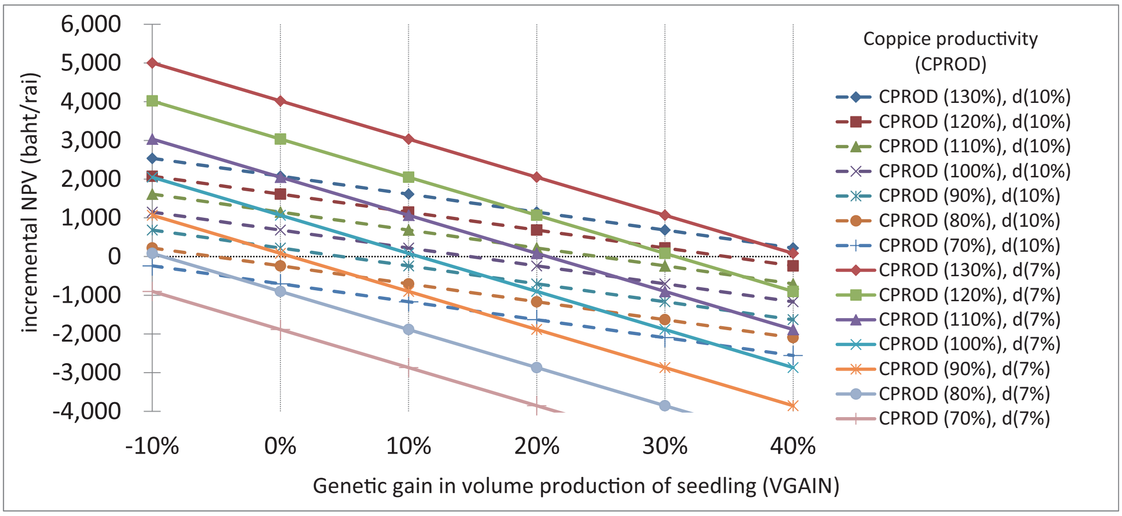
Variable	Unit	Description	Assumptions for variables		
			Base value	Range	Reference
CPROD	%	The percentage change in productivity of coppices in relation to the first rotation yield	100	80-120	Whittock et al.(2004)
VGAIN	%	The percentage genetic gain in volume production of seedlings over the first rotation	20	0-40	Whittock et al.(2004)
r	%	The percentage cost gain in land preparation, slash and burn to plant seedlings over the first rotation	50	0-100	Whittock et al.(2004)
LogPrice5	baht/m^3	The teak log price yielded at the 5 years old	1,500	1,350-1,650	RFD(2006)
LogPrice10	baht/m^3	The teak log price yielded at the 10 years old	3,000	2,700-3,300	RFD(2006)
LogPrice15	baht/m^3	The teak log price yielded at the 15 years old	5,000	4,500-5,500	RFD(2006)
LogPrice20	baht/m^3	The teak log price yielded at the 20 years old	7,000	6300-7700	RFD(2006)
d	%	Discount rate	10	8-12	Niskanen (1998)
Y	m^3/rai	Yield volume	-	-	-

Table 5. Rank correlations for NPVs including incremental NPV

Rotation period 15 years; plant spacing 4 m × 4 m				
Variable	1R	2R seedling	2R coppice	incremental NPV
CPROD	-	-	0.21	0.67
VGAIN	-	0.19	-	-0.66
r	-	-0.06	-	0.16
d	-0.92	-0.92	-0.91	0.17
LogPrice5	0.08	0.07	0.07	-0.02
LogPrice10	0.19	0.16	0.17	-0.01
LogPrice15	0.33	0.29	0.30	-0.03
Rotation period 15 years; plant spacing 3 m × 3 m				
Variable	1R	2R seedling	2R coppice	incremental NPV
CPROD	-	-	0.22	0.67
VGAIN	-	0.20	-	-0.67
r	-	-0.06	-	0.15
d	-0.91	-0.91	-0.90	0.15
LogPrice5	0.12	0.11	0.11	-0.02
LogPrice10	0.19	0.17	0.17	-0.02
LogPrice15	0.32	0.27	0.28	-0.03

Rotation period 20 years; plant spacing 4 m × 4 m				
Variable	1R	2R seedling	2R coppice	incremental NPV
CPROD	-	-	0.10	0.66
VGAIN	-	0.09	-	-0.65
r	-	-0.02	-	0.10
d	-0.97	-0.97	-0.97	0.27
LogPrice5	0.04	0.04	0.04	0.00
LogPrice10	0.09	0.08	0.08	-0.01
LogPrice15	0.10	0.09	0.09	-0.01
LogPrice20	0.19	0.17	0.17	-0.03
Rotation period 20 years; plant spacing 3 m × 3 m				
Variable	1R	2R seedling	2R coppice	incremental NPV
CPROD	-	-	0.10	0.66
VGAIN	-	0.10	-	-0.65
r	-	-0.02	-	0.11
d	-0.96	-0.97	-0.96	0.24
LogPrice5	0.04	0.04	0.04	0.00
LogPrice10	0.09	0.08	0.08	-0.01
LogPrice15	0.10	0.09	0.09	-0.01
LogPrice20	0.20	0.18	0.18	-0.03

(a) Rotation period 15 years; plant spacing 4 m × 4 m



(b) Rotation period 15 years; plant spacing 3 m × 3 m

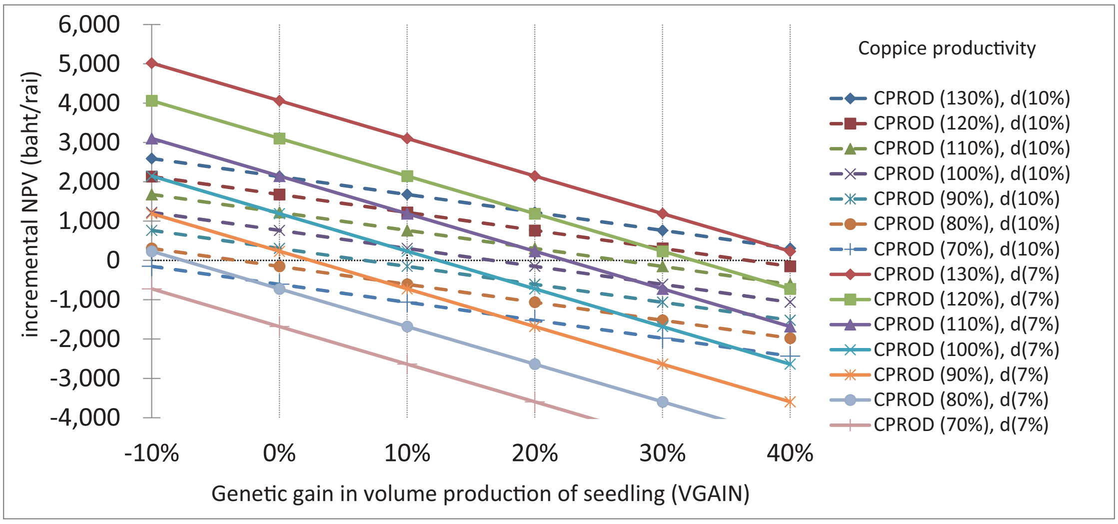
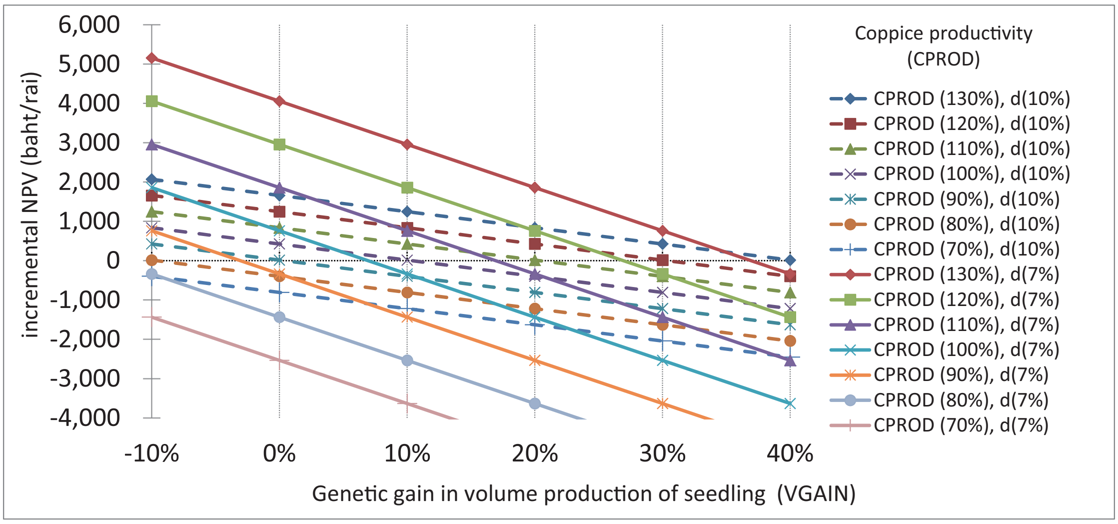


Fig. 1. Relationship between the combination of coppice productivity, seedling genetic gain and incremental NPV

(c) Rotation period 20 years; plant spacing 4 m × 4 m



(d) Rotation period 20 years; plant spacing 3 m × 3 m

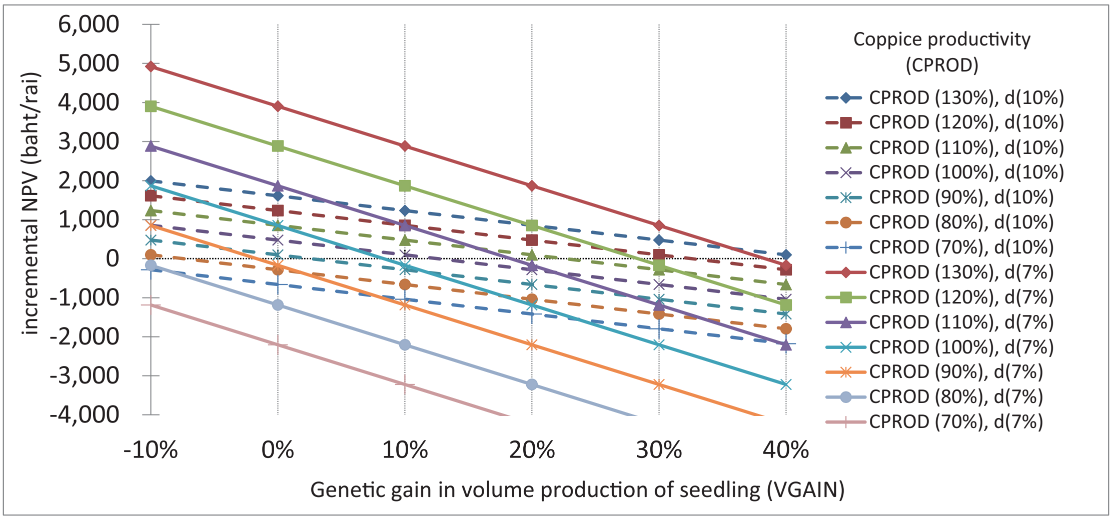


Fig. 2. Relationship between the combination of coppice productivity, seedling genetic gain and incremental NPV (cont'd)

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