DOI: 10.17138/TGFT(7)193-199

ILC2018 Keynote paper*

Dual use of leucaena for bioenergy and animal feed in Thailand

Uso de leucaena para bioenergía y alimentación de ganado en Tailandia

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Abstract

Leucaena is a dual-purpose plant suitable for producing both biofuel and feed for livestock (dairy and beef cattle, buffalo and goats). It has a high woody stem yield under repeated cutting and has a suitable chemical composition for excellent heat generation on combustion. Yields of leaf, which is a by-product of this process, are also high and the leaf has high nutritive value as an animal feed. Tarramba appears the highest yielding cultivar available, and many hybrid lines show excellent potential. Plant spacing of 1 × 0.50 m is recommended with cutting not more frequently than once a year. Harvesting of the crop should be carried out as a compromise between the needs for biofuel and livestock feed. On infertile soils application of at least 750 kg triple superphosphate, 188 kg KCl and 188 kg gypsum/ha/yr is recommended. Some limitations on growing and the management of leucaena are discussed.

Keywords: Dual-purpose crops, energy production, fodder shrubs.

Resumen

Leucaena leucocephala es una planta de doble propósito que puede producir tanto biocombustible como forraje para el ganado (bovinos de carne y leche, búfalos y cabras). La biomasa leñosa, obtenida por cortes repetidos, es alta y, por su composición química, posee un elevado poder calorífico que hace a esta planta muy apta para la generación de calor vía combustión. La biomasa de hojas, un importante subproducto en la generación de biocombustible, es igualmente alta y posee un alto valor nutritivo para el ganado. Actualmente, Tarramba es el cultivar con mayor rendimiento disponible aunque muchas líneas híbridas muestran un excelente potencial. Se recomiendan siembras espaciadas de 1 × 0.50 m con cortes no más frecuentes que una vez al año. La cosecha debe llevarse a cabo teniendo en cuenta las necesidades de biocombustible y la alimentación del ganado. En suelos infértiles se recomiendan aplicaciones de al menos 750 kg de superfosfato triple, 188 kg de KCl y 188 kg de yeso/ha/año. Este trabajo también discute algunas limitaciones sobre el crecimiento y el manejo de la leucaena.

Palabras clave: Arboles forrajeros, biocombustible, cultivos de doble propósito.

Introduction

It is well known that energy resources in Thailand have declined significantly and the demand for energy is currently satisfied primarily by importing fuels such as natural gas, charcoal and oil. Alternative energy sources are needed to replace natural oil and gas, preferably renewable sources. One solution is to utilize and transform the available local biomass from trees and agricultural residues into less-expensive electrical energy. To avoid increasing the harvesting of fuel wood from local natural forests, an alternative is to establish tree farms to provide a continuous supply of woody biomass. Leucaena (*Leucaena leucocephala*) has poten-

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*Keynote paper presented at the International Leucaena Conference, 1–3 November 2018, Brisbane, Queensland, Australia.

tial for this purpose and as well as supplying wood for bioenergy production has the following advantages over other fast-growing trees: It can fix atmospheric nitrogen while other trees like Eucalypts cannot; and the leaves and young green stems are highly palatable and highly nutritious for animal feed. Leucaena leaves are more readily acceptable than e.g. Acacia leaves, while Eucalypt leaves are often refused by stock. Like other tree species it has a deep root system, making it drought-resistant and productive during the dry season, and it can reduce greenhouse gases through absorbing CO_2 from the atmosphere (Dalzell et al. 2006).

Growing leucaena for energy and forage

Varieties

An increasing array of cultivars and lines of leucaena are now available and many hybrids are being produced. Farmers are faced with the dilemma of what cultivars/ lines to plant.

Recommendation. Research in Thailand suggests that the recommended cultivars/lines of leucaena for combined use as biofuel and forage are Tarramba and the hybrid lines KU3, KU15, KU19, KU38, KU39, KU45, KU48 and KU56 (all KU lines were selected from F2 plants of the University of Hawaii´s KX2 hybrid). However, Tarramba is the only one with seed available at present, while seed production of the hybrids is still under investigation.

Research evidence. Tudsri et al. (2010) collected 65 leucaena lines from various parts of Thailand and some F2 hybrids from Hawaii for testing at the Kasetsart University Research Station (Pakchong) over a period of 3 years. Based on total biomass yields the 8 top-ranking lines were all hybrids (KU3, KU15, KU19, KU38, KU39, KU45, KU48 and KU56) out-yielding the native (naturalized) ecotypes and current commercial cultivars, Peru and Cunningham (Figure 1). Other trials on the same site compared cvv. Peru and Cunningham with cv. Tarramba (from Australia) and 2 hybrid lines (from Hawaii) planted at a spacing of 1 × 0.5 m and cut annually for 7 years. As shown in the other study, the introduced lines, Tarramba and the hybrids KU66 and KU19, produced more woody biomass (23.0–24.8 t DM/ha/yr), leaf dry matter (3.4–4.0 t/ha/yr) and total biomass (30.4–30.7 t DM/ha/yr) than Cunningham and Peru (Table 1; Figure 2).

In a further study, 5 varieties/lines of leucaena (Cunningham, Peru, Tarramba, KU17 and KU19) were compared at a spacing of 1 × 0.5 m and harvesting 3 years after planting (Sripongpakapun 2011). Again Tarramba had the greatest stem diameter (4.9 cm) and woody stem yield (29.6 t DM/ha/yr), while Cunningham had the lowest (3.7 cm and 11.6 t DM/ha/yr, respectively). Means for the 2 hybrid lines were intermediate but superior to Cunningham and Peru. However, leaf yields were similar in all lines (range of 0.6–1.0 t DM/ha/yr).

Figure 1. Native leucaena (left) and hybrid line (KU19) (right) 6 months after planting.

Figure 2. Cvv. Tarramba (left), Peru (middle) and Cunningham (right); plants one year old.

Spacing

Recommendation. Plant spacing for maximum yield in a dual-purpose leucaena plantation during the first 4 years after planting should not exceed 1 × 0.5 m. This provides both high stem and leaf production to satisfy high energy production and the by-product of nutritious animal fodder.

Table 1. Cumulative (7 years) leaf, woody stem and total dry matter yields, woody stem heating value and ash concentration plus leaf crude protein (CP) concentration in 5 leucaena cultivars/lines at Pakchong, Nakhon Ratchasima Province (Tudsri et al 2010, 2015; Rengsirikul et al. 2011).

Cultivar/line	Leaf (t/ha)	Woody stem (t/ha)	Total DM[1] (t/ha)	Heating value[2] (kcal/g DM)	Ash[2] (%)	Leaf CP[2] (%)
Tarramba	24.1	173.6	213.1	4.7	2.18	25.7
Cunningham	19.2	131.1	169.4	4.6	1.93	25.6
Peru	14.0	90.3	116.7	4.6	2.06	24.7
KU19	27.2	161.1	212.8	4.6	1.72	24.3
KU66	27.8	167.0	215.1	4.6	1.75	24.2

[1]Includes branches. [2]One sampling date.

Research evidence. Chotchutima et al. (2013) studied the effects of plant spacing (1 × 0.25, 1 × 0.5, 1 × 1, 1 × 1.5, 2 × 0.5 and 2 × 1 m) on growth, biomass production and wood quality of leucaena cut annually at 0.5 m above ground level during 2006–2010 at Pakchong, Nakhon Ratchasima province. Spacing had a significant effect on plant diameter at breast height and biomass yield with highest stem diameter at the widest spacing (2 × 1 m), while DM yields of leaf, stem and total biomass were highest at the narrowest spacing (1 × 0.25 m) (Table 2). Since the minimum diameter for logs required for the biomass gasification system is 2.5 cm (Arjhan et al. 2007), stems produced at the narrowest spacing may be unsuitable for this purpose. Additional disadvantages of this narrow spacing were the higher seed and planting costs than for wider spacings. The wider spacing not only requires less seed but also allows better mechanized access for weed control. The optimal plant spacing for leucaena will depend on the relative importance given to production of biofuel and leaf for livestock feeding.

Harvesting interval

Recommendation. Leucaena should not be harvested more frequently than annually to ensure satisfactory stem yields and stem diameter. At this frequency stem yields should be about 17.3 t DM/ha/yr and leaf yields about 2.3 t DM/ha/yr. The optimal time to harvest leucaena for biofuel and fodder production would appear to be early in the dry season (November) as stems and leaf dry quickly in the dry conditions, and the leaf can be used to supplement livestock during the period of poor pasture quality. Harvesting at this time allows slow dry season regrowth (November–February) followed by rapid growth with the onset of occasional rains in March–April and the wet season in May. On the other hand, optimal time for harvesting may become irrelevant since wood processing mills will require a regular supply of material.

Research evidence. Tudsri et al. (2010) reported that harvesting leucaena frequently (every 9 months) produced low yields of stems, which were thin (2.68 cm diameter), but high leaf yields, while delaying harvesting until 36 months increased main stem diameter and woody yields but markedly reduced leaf yields (Table 3). Despite the high yields of woody material with harvesting at 36 months, this strategy may not be suitable for Thai farmers who need an income annually. Therefore, the recommended initial harvesting age and inter-harvest interval for leucaena should be a compromise but at least 12 months after planting.

Fertilizer application

Like all crops, leucaena may benefit from fertilizer application depending on the particular soil type where the crop is established.

Table 2. Effects of plant spacing on stem diameter, cumulative (4 years) leaf, woody stem and total dry matter yields plus leaf crude protein (CP) concentration of cv. Tarramba at Pakchong, Nakhon Ratchasima Province (Tudsri et al. 2010; Chotchutima et al. 2013).

Spacing (m)	Stem diameter (cm)	Leaf (t/ha)	Woody stem (t/ha)	Total[1] (t/ha)	Leaf CP[2] (%)
1 × 0.25	2.6e[3]	10.4a	99.5a	119.4a	22.5a
1 × 0.50	3.1de	8.0b	93.9ab	110.0ab	23.8a
1 × 1.00	3.9bc	7.2b	79.5ab	94.5ab	22.9a
1 × 1.50	4.5ab	6.9b	73.0b	87.2b	24.1a
2 × 0.50	3.7cd	7.1b	83.0ab	98.3ab	23.2a
2 × 1.00	4.6a	7.9b	82.2ab	99.0ab	22.4a

[1]Includes branches. [2]One sampling date. [3]In a column, means followed by a common letter are not significantly different at $P<0.05$.

Table 3. Effects of cutting interval on stem diameter and cumulative leaf and stem dry matter yields, woody stem heating value and ash concentration plus leaf crude protein (CP) concentration of cv. Tarramba at Pakchong, Nakhon Ratchasima Province (Tudsri et al. 2010; Chotchutima 2015).

Cutting interval (months)	Stem diameter (cm)	Leaf (t/ha)	Woody stem (t/ha)	Heating value[1] (kcal/g DM)	Ash[1] (%)	Leaf CP[1] (%)
9 (8 cuts)	2.68c[2]	16.8	66.7b	4.4a	2.08a	25.2a
12 (6 cuts)	3.44b	13.8	97.0b	4.4a	1.98a	24.9a
18 (4 cuts)	4.57a	16.8	155.3a	4.5a	1.89a	24.5a
24 (3 cuts)	na[3]	12.3	166.1a	na	na	na
36 (1 cut)[4]	na	3.0	88.0	4.6a	2.01a	16.8b

[1]One sampling (at the end of first cycle). [2]In a column, means followed by a common letter are not significantly different at P<0.05. [3]na = not available. [4]Only one harvest and not included in statistical analyses except for CP, ash and heating value.

Recommendation. On Pakchong soil type, where soil P and K levels are 15 and 75 ppm, respectively, no applications of K, P and S are required. However, on infertile soils in northeast Thailand, which are grossly deficient in K (<10 ppm), P (<2 ppm) and S, applications of 188 kg KCl, 188 kg gypsum plus 750 kg triple superphosphate (TSP)/ha at planting and as annual dressings are suggested. As chemical fertilizers are expensive, it may be more cost-effective to apply animal manure at 20 t/ha (Tudsri et al. 2015).

Research evidence. In our research at the Buriram Livestock Research and Testing Station, Pakham district, Buriram Province, K was applied during the wet season each year to leucaena plants cut once a year for 4 years. All plots received the same amount of P and S. Plots receiving at least 94 kg KCl/ha produced significantly higher (>100% increase) leaf and woody stem yields than the treatment receiving no K annually (Table 4). Leucaena plants receiving no K had yellow leaves, stunted growth and some plants died (Figure 3). Therefore, application of at least 188 kg KCl/ha to leucaena at planting is recommended on infertile soils in lower northeast Thailand (Tudsri et al. 2015).

Table 4. Effects of potassium fertilizer on cumulative (4 years) leaf, woody stem and total dry matter yields plus leaf crude protein (CP) concentration of cv. Tarramba at Pakham, Buriram Province (Tudsri et al. 2015).

Fertilizer rates (kg KCl/ha/yr)	Leaf (t/ha)	Woody stem (t/ha)	Total[1] (t/ha)	Leaf CP[2] (%)
0	4.2b[3]	21.4c	28.5b	20.1
94	9.1a	42.9bc	58.2b	17.9
188	14.3a	78.2ab	101.4a	18.6
375	12.5a	86.4ab	105.7a	18.5
750	13.1a	104.7a	123.6a	19.5

[1]Includes branches. [2]One sampling date. [3]In a column, means followed by a common letter are not significantly different at P<0.05.

Figure 3. No potassium fertilizer (left) and 750 kg KCl/ha applied (right).

In another trial on the same site, significant responses of leucaena to P and S fertilizers were reported (Chotchutima et al. 2016). Over the 2 years of the study, stem diameter, leaf and woody stem DM yields increased progressively (>200 and 400% yield increases, respectively) to the highest level of TSP (750 kg/ha) applied (Table 5). Leucaena also responded to added S through increased stem diameter (59% increase) plus leaf (96%), woody stem (232%) and total dry biomass (200%) yields. Without S, leucaena yields were very low and plants appeared yellow and unhealthy (Figure 4). Therefore, applications of 750 kg TSP and 188 kg gypsum/ha/yr are recommended on these infertile soils. In contrast, on the Pakchong soil type in Pakchong district, Nakhon Ratchasima Province, there were no responses to P, K and S. Soils in these areas have P and K levels of 15 and 75 ppm, respectively.

Table 5. Effects of application of sulfur (S) and phosphorus (P) on stem diameter and cumulative (2 years) leaf and woody stem dry matter yields of cv. Tarramba at Pakham, Buriram Province (Chotchutima et al. 2016).

Fertilizer	Stem diameter (cm)	Leaf (t/ha)	Woody stem (t/ha)	Total[1] (t/ha)
S (kg gypsum/ha/yr)				
0	1.7b[2]	2.3a	7.1b	10.2b
187.5	2.7a	4.5a	23.6a	30.9a
P (kg TSP/ha/yr)				
0	1.8c	2.4c	8.7c	11.9c
94	2.1bc	3.0b	12.9bc	17.3bc
188	2.1bc	3.3b	14.4b	19.4b
375	2.3ab	3.3b	15.3b	20.5b
750	2.6a	4.9a	25.5a	33.3a

[1]Includes branches. [2]In a column, means followed by a common letter within main effects are not significantly different at $P<0.05$.

Figure 4. Cv. Tarramba fertilized with S (187.5 kg gypsum/ha) and P (750 kg TSP/ha) (left) and no S and P applied (right).

Heating values, ash and chemical composition of woody stems

Research evidence. Heating value of stems was similar for all cultivars/lines (4.6–4.7 kcal/g DM) (Table 1), cutting intervals of 9–36 months (4.4–4.6 kcal/g DM) (Table 3) and plant spacings (>4.5 kcal/g DM). Lewandowski and Kicherer (1997) suggested that ideally biomass used for bioenergy production should contain at least 3.35 kcal/g DM. Energy concentrations in all woody material in our studies exceeded this critical value.

Bakker and Elbersen (2005) suggested that ash concentration is critical in determining the value of plant material as a biofuel. All cultivars/lines in our studies had ash concentrations in woody stems of less than 3% regardless of age at harvest and plant spacing (Tables 1 and 3).

Concentrations of H, O, K, S and ADF had been reported by Rengsirikul et al. (2011) to be similar in all cultivars/lines tested by them, but the newly introduced cultivar/lines, Tarramba, KU19 and KU66 contained higher C concentrations than the current cultivars, Peru and Cunningham. On the contrary, concentrations of N, Ca, Mg and acid detergent lignin were higher in Tarramba, Peru and Cunningham than in KU19 and KU66, while both hybrids (KU19 and KU66) exhibited higher cellulose concentrations than the other cultivars. Low lignin concentration in the plant is an advantage for the cellulosic biomass because of the need to remove lignin (Moore et al. 2008). KU19 and KU66 are more suitable for bioethanol production than the other cultivars due to their lower lignin and higher cellulose concentrations in woody stems. N concentrations of the hybrids KU19 and KU66 are also lower than the maximum critical level for biofuel production (Obernberger et al. 2006).

Chemical composition of leaf as a by-product of biofuel production

Research evidence. The introduced varieties (Tarramba, KU19 and KU66) can provide a greater amount of wood for bioenergy production than the existing cultivars; the leaf yields and protein concentrations are also high, providing a ready source of protein for feeding livestock. Rengsirikul et al. (2011) demonstrated that CP concentrations in leaf tissue (24.2–25.7%) of these newly introduced varieties were equivalent to those of currently used cultivars, Peru and Cunningham (24.7–25.6%) (Table 1). While CP concentrations were not affected by plant spacing (Table 2), cutting interval had a direct negative effect on CP concentration. Delaying cutting from every 9 months to 36 months reduced the CP concentration from 25.2% to 16.8% (Table 3). However the latter concentration is still adequate for the minimum requirements of ruminant animals (8–12%) (Norton et al. 1994). Leucaena leaves are ideal protein supplements for animals and are fed widely. Mueuangporn et al. (2018) reported that providing a supplement of 1–1.5 kg of dry leucaena leaves to milking buffaloes fed on dry pangola grass plus a supplement of 2 kg of 16% CP concentrate increased milk yield by 5.4 kg/day (94% increase) over that of the control treatment (without leucaena supplementation). Furthermore, Maksiri et al. (2017) reported that concentrations of essential fatty acids in the form of Omega 3 in meat of goats fed forage sorghum plus leucaena were higher than in meat of those receiving a ration of forage sorghum plus meal concentrate.

Conclusion

Our research studies have revealed that growing leucaena (cv. Tarramba and hybrids) as a source of renewable energy for power generation while providing leaf material as a by-product for supplementing livestock (dairy cows, beef cattle, buffalo and goats) could be highly beneficial for Thai farmers. Tarramba appears the highest yielding of existing cultivars and a number of hybrids show great potential. Plant spacing of 1 × 0.50 m is recommended, with harvesting no more frequently than once a year. Harvesting strategies should be based on a compromise between the importance of biofuel production, fodder for livestock and the need for a regular income. Fertilizer strategy will depend on the soil types on which the crop is grown.

Acknowledgments

We are grateful to Professor J.L. Brewbaker, University of Hawaii, for providing the F2 seeds of hybrid KX2, Professor Max Shelton for suggestions and comments and PTT Research and Technology Institute, PTT Public Company Limited and National Research Council of Thailand for funding this research. We also express our thanks to the staff of the Suwanvajokkasikit Research Station and the Buriram Livestock Research and Testing Station for their assistance during the conduct of the studies.

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(Note of the editors: All hyperlinks were verified 27 January 2019.)

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(Accepted 9 October 2018 by the ILC2018 Editorial Panel and the Journal editors; published 31 May 2019)