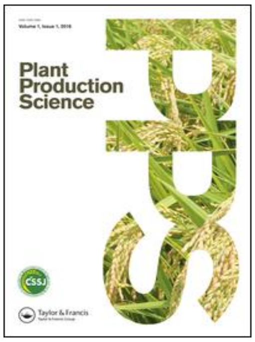

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Effects of trees planted on levees on rice yields in rain-fed paddy fields of northeast Thailand

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ABSTRACT
Trees are increasingly being planted on the levees of paddy fields of rice (*Oryza sativa* L.) in northeast Thailand. We investigated and compared the yields of rice grown in rain-fed paddies under and far from canopies of three different tree species: eucalyptus (*Eucalyptus* spp.), mango (*Mangifera indica* L.), and the indigenous neem tree (*Azadirachta indica* A. Juss). Rice yields tended to decrease near trees of all types at five sites, but there was no change in yields at the remaining 11 sites during the 3-year study. The reduced yields likely resulted from lower aboveground biomass, leading to fewer rice panicles and spikelets, particularly near trees with a dense canopy. Extremely low yields were observed near eucalyptus in paddy fields suffering from severe drought. These results, as well as information provided by farmers', suggest that eucalyptus trees may have detrimental effects on rice and should not be planted on the levees of paddy fields with relatively low productivity.

ABBREVIATION: CTP, location of rice cultivated close to the tree trunk; DBH, diameter at breast height; DHLB, diameter at HLB; FTP, location of rice cultivated far from the tree trunk; HLB, height of lowest live branch; PPFD, photosynthetic photon flux density

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Trees are commonly grown on the floors and levees of rain-fed paddy fields in northeast Thailand. Their origin, species composition, density, and utility for village life have been thoroughly studied and discussed (Grandstaff et al., 1986; Pendleton, 1943; Prachaiyo, 2000; Takaya & Tomosugi, 1972). Based on satellite images taken from 2003 to 2007, Watanabe et al. (2014) reported tree densities ranging from .8 to 446.6 trees ha^{-1}, depending on the land development history, topography, availability of natural forest resources, rainfall, and landholding size. Pham et al. (2015) discovered that total tree density in any given area is strongly correlated with the tree density on levees but not with that on the floors of paddy fields. Trees on levees are either planted for use in villages or sold, whereas trees on paddy floors are remnant species from forests that were present prior to land reclamation or naturally generated on remnant termite mounds. These trees are of economic value to the local villagers (Funahashi & Kosaka, 2015; Grandstaff et al., 1986).

Farmers believe that leaf litter from trees growing in paddy fields contributes to soil fertility (Pendleton, 1943; Pham et al., 2015). Vityakon and Dangthaisong (2005) demonstrated that such organic debris increases the supply of nutrients in the soil of paddy fields. Sae-Lee et al. (1992) and Vityakon et al. (1993) showed that soil fertility was progressively better with proximity to trees, whereas rice yields were lower adjacent to trees due to shading. Miyagawa et al. (2013) reported a nonsignificant relationship between grain yields and shading by trees, whereas rice yields near trees such as *Terminalia alata*, *Irvingia malayana*, *Morinda tomentosa*, and *Syzygium* sp. were higher than those at positions farther from trees in rain-fed paddy fields of central Laos. The trees investigated by Miyagawa et al. (2013) for their effect on rice yields in Laos were remnants, standing alone on the floors of paddy fields. Moreover, the trees were common species of plains in central Laos and northeast Thailand (Kokubo et al., 2015; Miyagawa et al., 2013; Prachaiyo, 2000), belonging to dry deciduous dipterocarp woodlands (Blasco et al., 1996).

Trees on paddy floors are often removed to accommodate the mechanization of rice cultivation, whereas those on levees have been increasing after the removal of remnant trees since the 1980s in northeast Thailand (Miyagawa, 1996; Pham et al., 2016). Eucalyptus (*Eucalyptus* spp.) trees are often planted on the levees of paddy fields. This species was introduced to Thailand in 1946 and to the northeast

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region of the country in 1964 (Thaiutsa & Taweesuk, 1987). Farmers grow these trees in rows on levees or in forest plantations, and harvest them after approximately 5 years for sale to paper factories (Funahashi & Kosaka, 2015; Thaiutsa & Taweesuk, 1987; Ubukata, 2001). There are reports of harmful effects of eucalyptus on the growth and yields of rice grown close to them (Funahashi & Kosaka, 2015; Pham et al., 2015), although some farmers value the contribution of their fallen leaves to soil fertility (Pham et al., 2015). However, there are no reports that prove the effects of eucalyptus and other tree species planted on levees on rice yields based on cutting surveys. Therefore, we investigated this issue, considering the potential effects of three different tree species on the growth and yields of rice grown in rain-fed paddy fields in northeast Thailand.

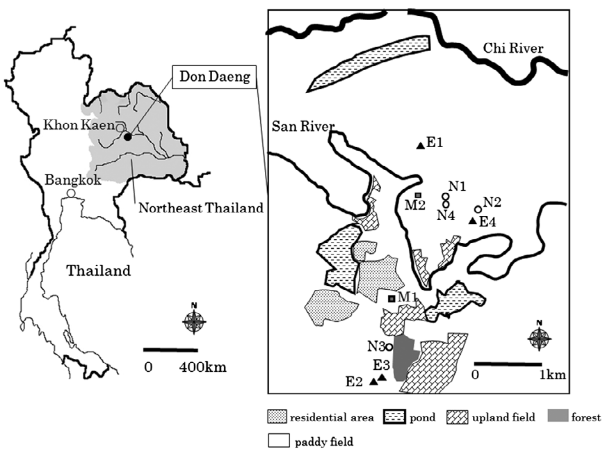

Figure 1. The location of Don Dang village (left) and the mango (M), eucalyptus (E), and neem (N) tree study sites in the paddy fields (right). The numbers following the tree name indicate the study site of each tree. Source: Author.

1. Materials and methods

1.1. Study site

This study was conducted from 2011 to 2013 in paddy fields in Don Daeng village, Khon Kaen province, which is located in the hilly areas and flood plains of the Chi River, a tributary of the Maekhong River in northeast Thailand (Figure 1). The village is typical of rice-growing villages in the area, where rice cultivation has been studied by one of the authors since 1981 (Miyagawa et al., 2006). Ten treed sites were selected for the study with the permission from the landowners. Two sites had mango trees (*Mangifera indica* L.; called 'mamuan' locally), and four sites had eucalyptus trees (called 'yuka' locally) planted in a row on the levees of paddy fields. Four sites had native neem trees (*Azadirachta indica* A. Juss; called 'sadao' locally), which were used to compare the effects of these trees with the other two species (Figure 1). The trees were spaced 7.1–9.7 m and 2.3–3.5 m apart for mango and eucalyptus, respectively (Table 1, Figure 2(a) and (b)). Neem trees grew naturally on both floors (sites 1 and 3) and on levees (sites 2 and 4) (Figure 2(c)). Mango trees had been planted by the owners 15–25 years ago, while the eucalyptus trees had been planted 5–10 years ago. The trees were planted for the consumption and sale of fruit (mango) and wood (eucalyptus). Neem trees provide shade and are a source of firewood.

At most of the sites, rice was directly seeded in June and July 2011 and from May to August 2012 and 2013, whereas rice was transplanted at neem tree site 4 in August 2011, mango tree site 2 in August 2012, and mango site 1 in August 2013. Rice was harvested in early to mid-November at every site in all three years. The rice cultivars RD6 or KDML105 were used for all sites, which are photosensitive and show almost the same heading stage independent of planting season.

Table 1. Characteristics of trees.

Tree	Site	*N*	Tree height (m)	DBH (cm)	HLB (m)	DHLB (cm)	Crown depth (m)	Crown area (m^2)	PPFD ratio[a]	Years after planting
Mango	1	6	5.2 ± .3[b]	33.1 ± 2.7	1.7 ± .1	11.3 ± 2.8	3.6 ± .3	24.6 ± 5.5	.48 ± .2	25
	2	6	5.9 ± .4	37.4 ± 8.6	2.4 ± .4	16.4 ± 3.2	3.5 ± .6	38.9 ± 8.3	.12 ± .0	15
Eucalyptus	1	3	14.7 ± .8	26.0 ± 2.1	1.7 ± .2	3.5 ± .9	13.0 ± 1.0	13.4 ± 2.4	.58 ± .1	6
	2	3	12.1 ± 1.3	28.4 ± 5.8	2.1 ± .3	4.1 ± .6	10.0 ± 1.1	28.7 ± 7.0	.51 ± .0	5
	3	3	12.3 ± 1.6	42.4 ± 15.9	2.6 ± .7	6.5 ± 3.0	9.7 ± 2.1	14.4 ± 6.5	.58 ± .2	10
	4	3	13.9 ± 1.5	38.7 ± 8.0	1.5 ± .4	4.8 ± .2	12.4 ± 1.3	18.5 ± 1.2	.42 ± .2	10
Neem[c]	1–4	4	10.0 ± 1.5	67.8 ± 13.3	2.1 ± .6	23.0 ± 14.5	7.9 ± 1.5	48.0 ± 20.3	.50 ± .1	4–100

	Site	Total No. of trees on levee	Average distance between trees (m)
Mango	1	10	9.7
	2	15	7.1
Eucalyptus	1	21	2.3
	2	12	3.5
	3	6	2.7
	4	17	2.7

N, the number of sample trees at each site.
DBH, diameter at breast height; HLB, height of lowest live branch; DHLB, diameter at HLB; PPFD, photosynthetic photon flux density.
[a]PPFD at points close to trees divided by that far from trees. [b]Mean ± standard error. [c]Neem trees grew naturally on the floors or levees of paddy fields at the four sites.

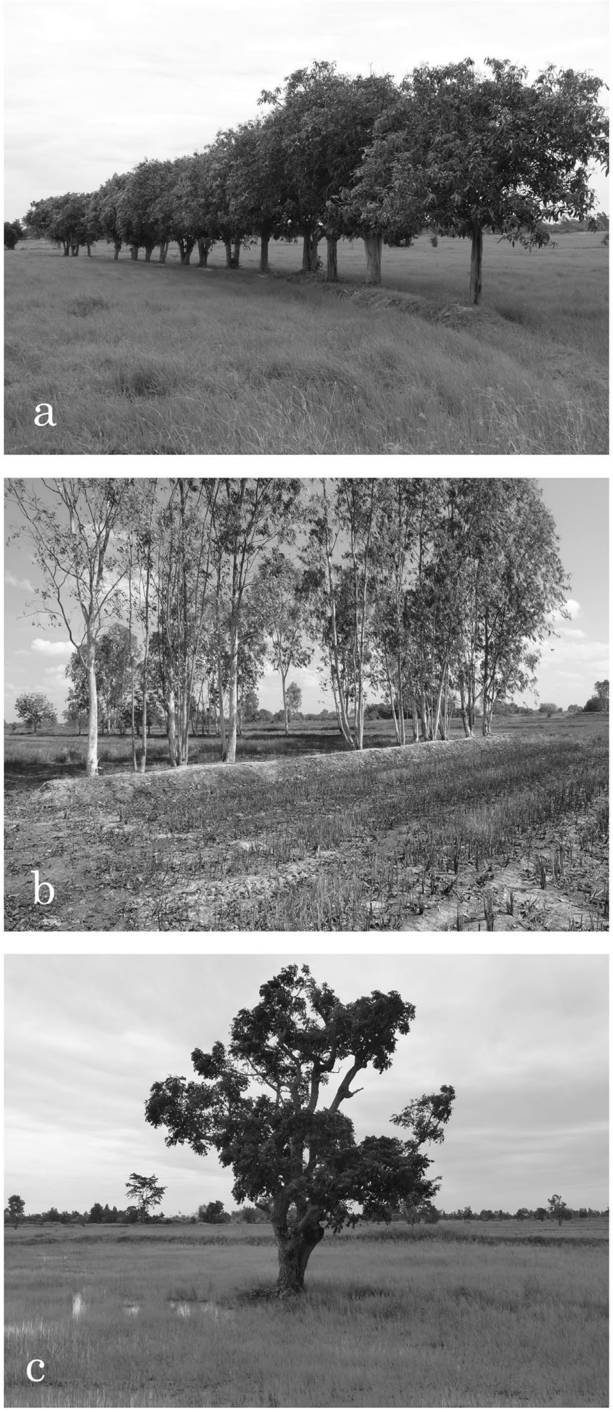

Figure 2. Mango tree at site 2 (a), eucalyptus tree at site 1 (b), and neem tree at site 1(c).

Chemical fertilizers were applied to all of the paddy fields every year, and farmers did not change the rate of fertilizer application based on proximity to trees. According to the monthly precipitation measured at Khon Kaen Weather Station, located ~10 km northwest of Don Daeng, precipitation was highest in 2011 and lowest in 2013 (Table 2). Excessive rainfall in September 2011 caused flooding in the lower paddy fields, and low rainfall from July to September 2012 caused drought in the higher elevation paddy fields.

1.2. Measurement and data collection

The height, diameter at breast height (DBH), height of the lowest branch (HLB), diameter at HLB (DHLB), and area of tree crowns were measured in 2011 and 2012. Tree height was measured with a laser distance meter (Truepulse 360, Laser Technology, Inc.). Photosynthetic photon flux density (PPFD) was measured around rice plants planted close to a tree (CTP), 1 m from the tree trunk, or far from a tree (FTP), where the effects of the tree would not be observed. PPFD was measured once per tree around noon on 8–12 September 2011, 7–8 August 2012, and 13–20 August 2013 in clear weather using a quantum light sensor (3668I6 Quantum Light 6 Sensor Bar connected to 3415FX Light Sensor Reader, Spectrum Technologies, Inc.), with 6–24 replications at each location.

To determine the influence of trees on the chemical properties of topsoil, samples (three replicates) were collected at the CTP and FTP at site 2 (mango tree) and site 4 (eucalyptus tree) before planting rice in 2013. Total carbon (TC) and total nitrogen (TN) contents were measured with an NC analyzer (Sumigraph NC-95A, SCAS, Osaka, Japan). The available P_2O_5 content was measured using Truog's method, which is usually employed for the quantitative analysis of available P_2O_5 in paddy field soil with a high organic matter content (Shibahara & Inubushi, 1997).

Yield surveys were conducted in early November of 2011, 2012, and 2013. Rice was harvested from a 1.5-m-diameter circle at four CTP sites and four FTP sites. Because of the short harvesting season dependent on the maturity of the above-mentioned cultivars and the necessity of conducting measurements rapidly before the rice harvest with combine harvesters, we were unable to conduct multiple measurements at different distances from the tree trunk. The apparent effects of trees were measured by

Table 2. Monthly precipitation (mm) in the rainy season at Khon Kaen Weather Station.

Year	April	May	June	July	August	September	October	November	Total
2011	48	110	157	271	226	369	185	12	1378
2012	153	231	98	99	232	136	34	30	1012
2013	7	117	56	358	180	215	44	1	979

subtracting the value at the FTP [T(f)] from that at the CTP [T(c)]. For trees planted on levees, rice was harvested at four points near a part of the same levee with no trees and at four points far from the levee to estimate the net effect of trees growing on levees. These locations were selected in areas where rice growth far from trees was similar to that at the FTP sites. The effects of levees were obtained by subtracting the value far from levees [L(f)] from the value close to levees [L(c)]. Rice yields from flooded paddy fields with eucalyptus trees were not assessed in 2011, and yields in paddy fields with mango trees in 2012, as well as several other sites over the three years, were not recorded due to early harvesting by farmers. The owners of the paddy fields with trees were interviewed during the survey period regarding their concerns about the effects of trees on paddy field soil, rice growth, and tree management.

Significant differences among means were identified using a one-way analysis of variance of the PPFD ratios among tree species and *t*-tests for soil chemical properties and rice yields between the CTP and FTP sites. A correlation analysis was conducted using Pearson's correlation coefficients.

2. Results and discussion

2.1. Effects of trees on soil fertility and rice yields

The mango trees were shorter than the other two tree species (Table 1). Eucalyptus trees had taller but more slender trunks, longer crown depth, and a smaller crown area than the other two species. The crowns of mango and eucalyptus trees covered paddy fields 2–3 m from the levees. There were no differences in the PPFD ratio among the three tree species, although the ratio at the site 2 of the mango trees was very low. The PPFD ratio was calculated by dividing the PPFD at a CTP by PPFD at the respective FTP.

The effects of trees on the chemical properties of soil in the paddy fields are shown in Table 3. The TC, and TN values of soil were significantly higher at the mango CTP site than at the FTP site, whereas pH (H_2O) was significantly higher at the mango FTP site than at the CTP site. The pH (KCl) was significantly higher at the eucalyptus CTP site compared to its FTP site.

The effects of trees on rice grain yields are shown in Table 4. Values at the FTP sites and points far from levees without trees were similar to those obtained from a cutting survey conducted from 2002 to 2004 (Miyagawa et al., 2009). Apparent grain weights were significantly lower at the CTP sites than the FTP sites for mango (site 2) in 2011, eucalyptus (site 4) and neem (site 2) in 2012, and mango (site 2), eucalyptus (site 1), and neem (site 2) in 2013. Net grain weight, which represented the levee effect removed

Table 3. Difference in soil chemical properties between points close to and far from trees.

Properties	Trees	Points	Mean	SD	Significance
pH (H_2O)	Mango[a]	Close	5.55	.01	5%
		Far	5.77	.13	
	Eucalyptus[b]	Close	5.30	.03	ns
		Far	5.20	.10	
pH (KCl)	Mango	Close	4.16	.04	ns
		Far	4.20	.15	
	Eucalyptus	Close	3.87	.03	5%
		Far	3.79	.02	
TC (g kg^{-1})	Mango	Close	10.97	.50	1%
		Far	7.21	1.11	
	Eucalyptus	Close	11.14	.74	ns
		Far	9.98	1.40	
TN (g kg^{-1})	Mango	Close	1.38	.06	5%
		Far	1.17	.10	
	Eucalyptus	Close	1.43	.05	ns
		Far	1.43	.09	
Available P_2O_5 (mg kg^{-1})	Mango	Close	14.73	2.06	ns
		Far	10.70	1.85	
	Eucalyptus	Close	7.67	.85	ns
		Far	8.47	1.25	

[a]Mango at site 2,
[b]Eucalyptus at site 4.

from apparent grain weight, was significantly lower at CTP sites than at FTP sites for mango (site 2) in 2011, neem (site 2) in 2012, and mango (site 2), eucalyptus (site 4), and neem (site 2) in 2013. There were no significant apparent and net tree effects, or enhanced effects, on rice grain yields for the remaining tree species/site combinations.

The effects of trees on the number of spikelets per unit area are shown in Table 5. The apparent number of spikelets was significantly lower at the CTP sites than at the FTP sites for mango (site 2) in 2011 and 2013. The net number of spikelets, which excluded the levee effect from the apparent number of spikelets, was significantly lower at the CTP sites than at the FTP sites for mango (sites 1 and 2) in 2011, and mango (site 2), eucalyptus (site 4), and neem (site 2) in 2013. There were no significant apparent or net tree effects for the remaining tree species/site combinations.

The effects of trees on the percentage of ripening grains are shown in Table 6. The apparent percentage of ripening grains was significantly lower at the CTP sites than at the FTP sites for mango (site 2) in 2011, eucalyptus (site 4) in 2012, and mango (site 2) and eucalyptus (site 1) in 2013. The net percentage of ripening grains, which excluded the levee effects from the apparent percentage of ripening grains, was significantly lower at the CTP sites than at the FTP sites for mango (sites 1 and 2) in 2011, and mango (site 2) and eucalyptus (sites 1 and 2) in 2013. There were no significant differences for the remaining tree species/site combinations.

There was a significant relationship between net grain weight per unit area and the net number of spikelets per unit area at the CTP sites ($r = .836$, $p < .01$), the net number of panicles per unit area (data not shown;

Table 4. Effects of trees on grain weight of rice (g m^{-2}).

Year	Tree	Site	Tree(T)/Levee(L)	Far (f) Mean	Far (f) SE	Close (c) Mean	Close (c) SE	Apparent tree effect[a]	†	Levee effect[b]	†	Net tree effect[c]	†
2011	Mango	1	T	170.0	42.5	205.6	82.4	35.6	ns	69.5	ns	−33.9	ns
			L	280.2	101.0	349.7	31.6						
	Mango	2	T	153.4	27.2	18.8	13.3	−134.6	**	−30.6	ns	−104.0	**
			L	118.4	62.1	87.7	19.5						
	Neem[#]	3	T	259.7	78.6	201.7	65.5	−58.0	ns	–		−58.0	ns
			L	–	–	–	–						
	Neem	4	T	192.8	95.1	274.5	38.4	81.7	ns	21.4	ns	60.2	ns
			L	209.1	81.5	230.6	84.8						
2012	Eucalyptus	2	T	374.6	128.0	370.4	89.0	−4.2	ns	133.2	ns	−137.4	ns
			L	363.3	58.9	496.5	140.6						
	Eucalyptus	3	T	266.7	27.5	222.6	64.2	−44.1	ns	62.5	ns	−106.6	ns
			L	276.2	–	331.6	62.2						
	Eucalyptus	4	T	27.9	15.5	2.5	2.8	−25.4	*	–		–	
			L	NA	NA	26.6	9.6						
	Neem[#]	1	T	96.7	54.2	103.7	93.7	7.0	ns	–		7.0	ns
			L	–	–	–	–						
	Neem	2	T	298.9	22.9	190.4	6.4	−108.5	*	21.3	ns	−129.8	*
			L	310.6	34.9	331.9	36.6						
	Neem[#]	3	T	300.1	68.6	279.0	21.9	−21.1	ns	–		−21.1	ns
			L	–	–	–	–						
2013	Mango	2	T	413.1	62.6	152.1	68.1	−261.0	**	26.4	ns	−287.4	**
			L	350.0	50.1	376.4	72.1						
	Eucalyptus	1	T	268.3	76.1	131.6	30.4	−136.6	**	−71.8	**	−64.8	ns
			L	266.1	52.0	194.3	15.3						
	Eucalyptus	2	T	291.5	75.6	290.2	123.8	−1.3	ns	24.2	ns	−25.6	ns
			L	328.3	137.1	352.6	84.0						
	Eucalyptus	3	T	313.0	69.1	341.2	9.6	28.2	ns	80.8	ns	−52.5	ns
			L	349.8	48.6	430.6	62.0						
	Eucalyptus	4	T	239.9	76.6	88.9	58.4	−151.0	ns	109.5	ns	−260.5	**
			L	297.6	54.1	407.1	89.6						
	Neem	2	T	244.2	33.3	143.7	90.1	−100.5	*	60.8	ns	−161.3	*
			L	246.1	48.5	306.9	111.7						
	Neem[#]	3	T	295.2	56.9	262.8	28.2	−32.5	ns	–		−32.5	ns
			L	–	–	–	–						

[a]T(c) − T(f).
[b]L(c) − L(f).
[c]T(c) − T(f) − {L(c) − L(f)}.
[#]On the floor of the paddy field.
[†]Significance of the effects of a, b, and c at the 5% (*) and 1% (**) probability levels. ns, nonsignificant.

$r = .755$, $p < .01$) and net total dry weight of rice plants above ground (data not shown; $r = .755$, $p < .01$), whereas there were no significant relationships between net grain weight and net percentage of ripened grains ($r = -.072$, $p > .05$), and net 1000-grain weight (data not shown; $r = .276$, $p > .05$). The correlation coefficients between net total dry weight of rice plants above ground and the net number of panicles per unit area were .632 ($p < .01$). These results suggest that the reduction of rice yields at points close to the tree were caused by the smaller number of spikelets produced per unit area, which were mainly the result of a smaller number of panicles due to the plants producing less biomass compared to rice grown further from the trees.

There was no significant relationship between PPFD ratio and the ratio of net grain weight at CTP sites to grain weight at FTP sites ($r = .515$, $p > .05$). Although the PPFD ratios obtained in this study were qualified based on the potential seasonal change from rainy to dry season, relatively low PPFD ratios may have reflected significant negative net tree effects on grain weight at two mango sites (site 2 in 2011 and 2013) and one eucalyptus site (site 4 in 2013) (Table 4). Although soil close to levees with mango trees was more fertile than soil far from the trees, an extreme shading effect caused by the tree canopy may have resulted in low rice yields near levees with trees. Significantly lower yields near neem at site 2 in 2012 and 2013 might have been due to a smaller number of spikelets and lower percentage of ripening grains, although their PPFD ratios were not particularly low (.54 in 2012 and .56 in 2013). Extremely low grain weights at the CTP site (2.5 g m^{-2}) and FTP site (27.9 g m^{-2}) were obtained in a paddy field that suffered from severe drought at site 4 (eucalyptus) in 2012. This may suggest that eucalyptus trees hinder rice yields in paddy fields under unfavorable conditions. By comparison, neem trees appeared to have no significant negative effect on rice yields under such conditions (e.g. site 1 in 2012). The basis for these differences among tree species should be studied further.

Table 5. Effects of trees on the number of spikelets (m^{-2}).

Year	Tree	Site	Tree(T)/Levee(L)	Far (f)		Close (c)		Apparent tree effect[a]	†	Levee effect[b]	†	Net tree effect[c]	†
				Mean	SE	Mean	SE						
2011	Mango	1	T	13,365	2337	10,559	3234	−2807	ns	2072	ns	−4879	*
			L	6648	731	8720	4078						
	Mango	2	T	7677	1248	1697	749	−5979	**	−3108	*	−2871	**
			L	6785	2719	3677	992						
	Neem[#]	3	T	9960	2008	8125	2474	−1835	ns	–		−1835	ns
			L	–	–	–	–						
	Neem	4	T	9234	4197	13,225	816	3991	ns	894	ns	3097	ns
			L	9821	2986	10,715	4438						
2012	Eucalyptus	2	T	16,098	3945	16,422	1777	324	ns	2729	ns	−2404	ns
			L	17,202	4538	19,931	5472						
	Eucalyptus	3	T	14,348	3712	16,432	1556	2083	ns	2875	ns	−791	ns
			L	13,360	–	16,234	874						
	Eucalyptus	4	T	1548.3	813.7	302.1	304.6	−1246	ns	–		–	
			L	NA	NA	2340.8	327.8						
	Neem[#]	1	T	4664	1881	4383	4001	−281	ns	–		−281	ns
			L	–	–	–	–						
	Neem	2	T	13,506	1590	9258	684	−4248	ns	364	ns	−4612	ns
			L	15,528	1711	15,892	2489						
	Neem[#]	3	T	14,840	3275	14,155	1672	−685	ns	–		−685	ns
			L	–	–	–	–						
2013	Mango	2	T	14,912	1632	7715	1826	−7198	**	1568	ns	−8766	**
			L	14,606	1659	16,174	4610						
	Eucalyptus	1	T	11,602	3385	9090	2134	−2512	ns	−3600	ns	1088	ns
			L	12,136	1276	8536	574						
	Eucalyptus	2	T	10,985	2868	13,255	6074	2271	ns	1110	ns	1161	ns
			L	13,258	5026	14,367	3994						
	Eucalyptus	3	T	10,875	2891	12,062	1430	1188	ns	5265	*	−4077	ns
			L	12,158	1245	17,423	2398						
	Eucalyptus	4	T	8956	3145	3917	1952	−5039	ns	3697	ns	−8736	*
			L	12,304	1816	16,001	2486						
	Neem	2	T	10,508	2431	8534	3296	−1974	ns	3533	ns	−5507	*
			L	10,932	1158	14,464	2051						
	Neem[#]	3	T	12,164	2170	12,646	2741	482	ns	–		482	ns
			L	–	–	–	–						

[a]T(c) – T(f).
[b]L(c) – L(f).
[c]T(c) – T(f) – {L(c) – L(f)}.
[#]On the floor of the paddy field.
[†]Significance of the effects of a, b, and c at the 5% (*) and 1% (**) probability levels. ns, nonsignificant.

2.2. *Farmers' evaluations and management of trees*

We interviewed farmers about the relationship between trees and rice production, and they believed that fallen mango leaves promoted rice growth but that rice plants ultimately lodged due to shading by the dense mango canopy, and reduced yields near trees compared to open areas. Regarding eucalyptus trees, farmers said that fallen leaves improved soil fertility in years with optimal rainfall, but that the trees inhibited rice germination and yields at a distance of 1.8–3.6 m from trees. Within this proximity, tree roots absorbed nutrients and water, which negatively affected the available nutrients and water in paddy fields. The responses from farmers were consistent with previous reports (Funahashi & Kosaka, 2015; Pham et al., 2015). For neem trees, fallen leaves were perceived as favorable for soil fertility, but trees with large canopies induced rice lodging and delayed rice heading. This feedback was consistent with our results in general, although the soil fertility benefits from eucalyptus trees are unknown. These results support the need for further studies at a greater number of sites and over a longer period of time.

Lower tree branches, which likely inhibited rice growth at mango site 2, eucalyptus sites 1 and 2, and neem sites 1 and 2, are frequently pruned. However, significantly adverse effects on rice yields were consistently observed in this study, and such management seems to be insufficient to improve the yield of rice planted near trees.

3. Sustainability of tree planting in paddy fields

Our research did not indicate enhanced effects of trees planted on levees, or native trees growing in paddy fields, on rice grain yields, in contrast to results from Laos where four tree species were observed to enhance grain yields at the CTP of five sites over three years (Miyagawa et al., 2013). However, the tree species examined in that study differed from those in this study, and are not found in paddy fields at Don Daeng. Rice yields in rain-fed cultivation varied considerably among fields, influenced by various environmental factors (Miyagawa & Kuroda, 1988; Miyagawa et al., 2006). The grain yields at the FTP sites ranged from 27.9 to 413.1 g m^{-2} in our study, which corresponded to a similar range of 9.3–399.6 g m^{-2} observed in Laos (Miyagawa et

Table 6. Effects of trees on percentage of ripening grains.

Year	Tree	Site	Tree(T)/Levee(L)	Far (f)		Close (c)		Apparent tree effect[a]	†	Levee effect[b]	†	Net tree effect[c]	†
				Mean	SE	Mean	SE						
2011	Mango	1	T	85.8	3.4	80.0	6.1	−5.7	ns	4.8	ns	−10.5	**
			L	78.9	8.2	83.7	6.4						
	Mango	2	T	70.7	11.0	26.3	17.0	−44.4	**	8.4	ns	−52.7	**
			L	61.3	16.6	69.7	8.0						
	Neem[#]	3	T	74.8	16.3	74.8	7.7	0.0	ns	–		0.0	ns
			L	–	–	–	–						
	Neem	4	T	69.7	10.4	68.1	5.2	−1.7	ns	5.1	ns	−6.7	ns
			L	63.8	5.0	68.9	10.3						
2012	Eucalyptus	2	T	72.2	12.8	71.8	17.1	−0.4	ns	5.2	ns	−5.6	ns
			L	71.1	7.7	76.3	6.6						
	Eucalyptus	3	T	56.9	13.0	35.7	19.0	−21.2	ns	3.8	ns	−25.0	ns
			L	62.0	–	61.9	12.3						
	Eucalyptus	4	T	31.8	1.5	14.5	7.2	−17.4	*	–		–	
			L	NA	NA	31.3	9.1						
	Neem[#]	1	T	62.4	23.7	79.1	9.5	16.6	ns	–		16.6	ns
			L	–	–	–	–						
	Neem	2	T	67.7	9.2	66.2	1.3	−1.5	ns	10.2	ns	−11.7	ns
			L	63.0	2.2	73.2	8.3						
	Neem[#]	3	T	65.3	14.5	60.5	7.2	−4.8	ns	–		−4.8	ns
			L	–	–	–	–						
2013	Mango	2	T	77.2	6.4	53.5	20.8	−23.7	*	1.4	ns	−25.1	*
			L	63.0	5.6	64.4	11.5						
	Eucalyptus	1	T	75.9	5.2	45.0	18.4	−30.9	**	7.4	ns	−38.3	**
			L	68.6	10.6	76.0	5.7						
	Eucalyptus	2	T	76.2	12.7	67.3	10.4	−8.9	ns	8.2	ns	−17.1	*
			L	68.5	24.0	76.7	10.1						
	Eucalyptus	3	T	82.1	9.1	80.0	9.0	−2.1	ns	−20.5	*	18.4	ns
			L	80.5	9.7	60.0	5.8						
	Eucalyptus	4	T	84.9	4.0	57.3	24.4	−27.5	ns	5.8	ns	−33.3	ns
			L	73.0	8.6	78.7	6.5						
	Neem	2	T	61.0	15.9	33.4	22.1	−27.6	ns	−7.2	ns	−20.3	ns
			L	61.9	15.7	54.7	30.2						
	Neem[#]	3	T	65.3	19.0	50.4	20.2	−14.9	ns	–		−14.9	ns
			L	–	–	–	–						

[a]T(c) − T(f).
[b]L(c) − L(f).
[c]T(c) − T(f) − {L(c) − L(f)}.
[#]On the floor of the paddy field.
†Significance of the effects of a, b, and c at the 5% (*) and 1% (**) probability levels. ns, nonsignificant.

al., 2013). However, the mean (247.4 g m^{-2}) in this study was significantly higher than that (200.4 g m^{-2}) in Laos. An enhancing effect of trees might be difficult to observe in higher productivity paddy fields owing to frequent rice lodging. Trees on levees affected the yields of rice growing near the trees, but the effects varied by tree species and the condition of the field. According to the tree owners, income from selling eucalyptus reached some thousands of Thai Baht after 6–7 years of growing, while mango fruits were sold at markets, as well as providing food to the owners. It is important to identify trees that do not have deleterious effects on rice production in northeast Thailand, and more research is needed to develop appropriate management practices for both rice and tree yields.

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