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Efficacy, technical parameters and costs of applying insecticide using boom sprayers vs spray lances for controlling melon thrips in orchid nurseries in Thailand

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Abstract The application of a vertical boom sprayer and a self-propelled vertical boom sprayer gave similarly effective-control melon thrips when compared with a spray lance technique as a conventional sprayer in both field trials. In addition, the technical parameters (spray volume, spraying time spent, amount of insecticide and surfactant) and cost analysis for applying insecticide showed that the boom sprayers was reduced spray volume by 22.2±1.9% to 25.5±3.7%, spraying time spent by 40.2±1.5% to 63.9±1.8%, amount of insecticide and surfactant by 21.7±3.7% to 25.4±3.7%, and operational costs by 27.0±1.7% to 52.9±5.5% when compared with the spray lance. It revealed that the appropriate technique could increase spray application efficiency and achieve the real cost savings for orchid growers.

Keywords Spray boom, spray volume, spraying time spent, insecticide usage, Dendrobium

Introduction

Dendrobium hybrids are the main orchid plants grown commercially for cut flowers and potted plants in Thailand. In 2018, a total of 25,054 tons, (worth 66 million US dollars) were exported to Japan, America, Italy, Hong Kong, China and Taiwan (Office of Agricultural Economics, 2019) Melon thrips, *Thrips palmi* Karny (Thysanoptera: Thripidae), is the primary insect pest that commonly limits the economic production of Dendrobium hybrids in orchid nurseries (Kajita *et al*., 1992; Poonchaisri, 2001). As many as 74% of blooms are attacked by thrips when no insecticide is applied (Kienmeesuk and Tothong, 2000). Upon export, thrips infestation leads to rejection by quarantine inspectors (Department of Agriculture, 2007; Anonymous, 2009). A recent

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survey of orchid growers found that melon thrips is considered to be one of the most serious insect pests affecting cut orchids. Growers apply an average of 4–5 insecticide applications per month; approximately one-half of growers apply insecticides on a weekly basis (Srijuntra *et al*., 2016). Researchers further found that growers apply insecticides using a spray lance with an adjustable cone nozzle connected to a hydraulic sprayer at a coverage rate of 160 L/rai (0.16 ha) (Punyawattoe *et al*., 2019) Generally, this application method has only limited ability to produce uniform coverage throughout the orchid canopy, and the control efficacy depends on the operator's skill and effort (Wechakit *et al*., 2008; Punyawattoe *et al*., 2016). Recently, vertical boom sprayers have come into increasing use in greenhouses across Europe and USA (Nuyttens *et al*., 2004a; Sánchez-Hermosilla *et al*., 2013). Vertical boom sprayers provide effective control and safer time for workers (Nuyttens *et al*., 2004b; Nuyttens *et al*., 2009; Sánchez-Hermosilla *et al*., 2013). A shortage of labor and increasing operation costs are motivating interest in improving spray application techniques in orchid nurseries (Wechakit *et al*., 2008). However, efficacy measurements and cost analyses are still needed to inform orchid growers' decisions about adopting and implementing these new technologies. To optimize spraying techniques and to inform recommendations to growers, effectiveness and expenditure must be evaluated in field trials. The aim of this study was to compare the effectiveness of boom sprayers in *T. palmi* control in orchid nurseries, and to compare their costs. Specifically, we compared the amounts of insecticide application, the treatment costs, and the costs of various promotion techniques for communicating with farmers.

Materials and methods

Experimental set-up and spray application

The research was conducted at two commercial Dendrobium orchid nurseries in the Nakhonprathom and Nonthaburi provinces during August to October 2019. Three types of spray equipment were used: (a) a manually operated vertical boom sprayer, (b) a self-propelled vertical boom sprayer; each connected to a high-pressure pump with a high-volume application of 120 L/0.16 ha, and (c) a spray lance 0.40 m long fitted with a conventional cone nozzle connected to a high pressure pump sprayer with a high-volume application at 160 L/0.16 ha. The manually operated vertical boom sprayer covered a one-metre swath. The operator moved it from one end of the row to the other, spraying towards the left, and then back again. The self-propelled vertical boom sprayer covered a two-metre swath; the operator moved it along every other row, from the end of the row and back. Using the spray lance with a 0.5 m swath width, and both sides of the row of orchids were sprayed simultaneously, with normal practice.

Efficacy of a boom sprayer and spray lance against melon thrips

Each application trial was conducted in plots of 0.16 ha. Treatments were applied using the surfactant Tension T-7, and rotating between three recommended insecticides as follows:- the first and second applications comprised emamectin benzoate 1.92% EC at a concentration of 20 ml/20 L water, the third and the fourth applications comprised fipronil 5% SC at a concentration of 30 ml/20 L water, and the fifth and the sixth applications comprised imidacloprid 70% WG at a concentration of 15 g/20 L water. Prior to each of the six insecticide treatments, thrips density was assessed by collecting from 80 randomly selected inflorescences per plot. A threshold of 4 thrips per inflorescence was taken to indicate a need for spraying at that time (Srijuntra *et al*., 2019). Treatments were evaluated 72 h and again five days after each application by again collecting thrips from randomly selected inflorescences. Thrips population densities were compared using Student's t-test.

Analysis of technical parameters and cost

Operational parameters and application costs were collected data in six different times between August to October 2019. Technician time included the time spent preparing equipment, formulating insecticide, treating and cleaning which each activity was timed using a stopwatch. Operation cost was calculated from the lowest standard labour wage plus overhead costs in the area. The workers were divided into two groups: Thai and migrant workers. After application, the application equipment was weighed to determine how much product was left over, and hence the amount applied. The amount applied was converted into a baht value to compare the average product cost per area, using prices at local agricultural chemical suppliers.

Results

Efficacy of a boom sprayer and spray lance against melon thrips

The number of melon thrips and difference among treatments at an orchid nursery was inbvestigated as seen in Tables 1 and 2. Prior to treatment, the mean numbers of melon thrips per inflorescence of all treatments were not significantly differed. After the first treatment, the thrips population density showed the most fell when using the self-propelled vertical boom sprayer, and the least after using the spray lance. The later trial, the differences between application methods showed no significant differences between their associated population densities.

Table 1. Mean number of melon thrips (Mean ±SEM) and statistical analysis of the difference among treatments at an orchid nursery, Samphan district, Nakhon Pathom province, August–September 2019 (1st trial)

Timing of application	**Average No. of melon thrips/inflorescences**			***p* value**		
	Vertical boom	Self-propelled vertical boom	Spray lance	Vertical boom vs Self-propelled vertical boom	Vertical boom vs Spray lance	Self-propelled vertical boom vs Spray lance
Before application	5.6 ±1.5	5.3 ±1.5	5.8 ±1.6	0.09	0.62	0.30
After 1st application	1.5 ±0.8	1.3 ±0.9	1.6 ±0.7	0.11	0.20	0.04*[1/]
After 2nd application	1.6 ±0.6	1.4 ±0.8	1.7 ±0.5	0.10	0.26	0.03*
After 3rd application	1.3 ±0.6	1.4 ±0.8	1.7 ±0.5	0.62	0.03*	0.04*
After 4th application	1.4 ±0.6	1.2 ±0.9	1.5 ±0.6	0.32	0.43	0.11
After 5th application	1.7 ±0.6	1.5 ±0.9	1.8 ±0.6	0.31	0.42	0.13
After 6th application	1.6 ±0.7	1.6 ±0.8	1.7 ±0.7	0.76	0.55	0.50

[1/] Values in the same row followed no symbol are not significantly different at the 0.05 level, according to Student's t-test. **p* < 0.05; ***p* < 0.01

Analysis of technical parameters and costs

Analysis of technical parameters

The findings in both trials found that spray application affected the technical parameters (Tables 3 and 4). The spray lance delivered the highest spray volume, and followed by self-propelled boom and vertical boom. Lance spraying had used more insecticide and adjuvant, and followed by the self-propelled boom, and the vertical boom sprayer. Spraying was the slowest when using the lance more than using the self-propelled boom and vertical boom. Using the vertical and the self-propelled vertical booms reduced spray volume, spraying time, insecticide and surfactant usages compared with the lance. The comparison of self-propelled vertical boom with a vertical boom, it found that self-propelled vertical boom reduced spraying time, while it did not reduce the spray volume, insecticide and surfactant usages.

Table 2. Mean number of melon thrips (Mean ±SEM) and statistical analysis of the difference among treatments at an orchid nursery, Sainoi district, Nonthaburi province, September – October 2019 (2nd trial)

Timing of application	**Average No. of melon thrips/inflorescences**			***p* value**		
	Vertical boom	Self-propelled vertical boom	Spray lance	Vertical boom vs Self-propelled vertical boom	Vertical boom vs Spray lance	Self-propelled vertical boom vs Spray lance
Before application	4.6 ±1.5	4.9 ±1.5	4.3 ±1.2	0.19	0.37	0.08
After 1st application	1.1 ±0.8	1.2 ±0.9	1.4 ±0.9	0.65	0.09	0.33
After 2nd application	1.2 ±0.8	1.0 ±0.9	1.3 ±0.7	0.14	0.66	0.13
After 3rd application	1.0 ±0.9	0.9 ±0.8	1.2 ±0.8	0.69	0.13	0.02*[1/]
After 4th application	0.8 ±0.8	0.9 ±0.8	1.2 ±0.7	0.64	0.02*	0.08
After 5th application	1.2 ±0.6	1.1 ±0.6	1.3 ±0.6	0.35	0.60	0.17
After 6th application	1.1 ±0.6	0.8 ±0.7	1.2 ±0.4	0.06	0.30	0.001**

[1/] Values in the same row followed no symbol are not significantly different at the 0.05 level, according to Student's t-test. *$p < 0.05$; **$p < 0.01$

Technical cost analysis

The spray lance was the most expensive method of application, and followed by the vertical boom and self-propelled vertical boom, respectively. Using the vertical and self-propelled vertical booms reduced insecticide application costs by 27.0 ±1.7 and 52.9 ±5.5%, respectively (Tables 5 and 6).

Table 3. Technical parameters at an orchid nursery, Samphan district, Nakhon Pathom province, August–September 2019 (1st trial)

Details	Unit	Timing of application						Mean ±SEM
		1st	2nd	3rd	4th	5th	6th	
1. Technical parameters of a vertical boom sprayer								
1.1 Spray volume	L/0.16 ha	120	114	133	126	120	139	125.0 ±3.8
1.2 Spraying time spent (2 workers)	minute/0.16 ha	19	18	21	20	19	22	20.0 ±0.6
1.3 Amount of insecticide								
1.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	120	114	-	-	-	-	117.0 ±3.0
1.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	99	95	-	-	97.0 ±2.0
1.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	180	208	194.0 ±14.0
1.4 Amount of surfactant	ml/0.16 ha	18	17	20	19	18	21	19.0 ±0.6
2. Technical parameters of a self-propelled vertical boom sprayer								
2.1 Spray volume	L/0.16 ha	130	120	130	140	140	110	128.0 ±4.8
2.2 Spraying time spent (2 workers)	minute/0.16 ha	13	12	13	14	14	11	13.0 ±0.5
2.3 Amount of insecticide								
2.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	130	120	-	-	-	-	125.0 ±5.0
2.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	98	105	-	-	101.0 ±4.0
2.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	210	165	188.0 ±23.0
2.4 Amount of surfactant	ml/0.16 ha	20	18	20	21	21	17	19.0 ±0.7
3. Technical parameters of a spray lance								
3.1 Spray volume	L/0.16 ha	155	170	179	160	165	175	167.0 ±3.7
3.2 Spraying time spent (2 workers)	minute/0.16 ha	32	35	37	33	34	36	35.0 ±0.8
3.3 Amount of insecticide								
3.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	155	170	-	-	-	-	162.0 ±7.0
3.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	135	120	-	-	127.0 ±7.0
3.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	247	262	255.0 ±7.0
3.4 Amount of surfactant	ml/0.16 ha	23	25	27	24	25	26	25.0 ±0.6
4. Decreasing technical parameters								
4.1 a vertical boom vs a spray lance								
4.1.1 Spray volume	percent	22.6	32.9	25.7	21.3	27.3	20.6	25.1 ±1.9
4.1.2 Spraying time spent	percent	40.6	48.6	43.2	39.4	44.1	38.9	42.5 ±1.5
4.1.3 Insecticide	percent	22.6	32.9	26.7	20.8	27.1	20.6	25.1 ±1.9
4.1.4 Surfactant	percent	21.7	32.0	25.9	20.8	28.0	19.2	24.6 ±4.9
4.2 a self-propelled vertical boom vs a spray lance								
4.2.1 Spray volume	percent	16.3	29.4	27.4	12.5	15.2	37.1	23.0 ±4.0
4.2.2 Spraying time spent	percent	59.4	65.7	64.9	57.6	58.8	69.4	62.6 ±1.9
4.2.3 Insecticide	percent	16.1	29.4	27.4	12.5	15.0	37.0	22.9 ±4.0
4.2.4 Surfactant	percent	13.0	28.0	25.9	12.5	16.0	34.6	21.7 ±3.7

Table 4. Technical parameters at an orchid nursery, Sainoi district, Nonthaburi province, September – October 2019 (2nd trial)

Details	Unit	Timing of application						Mean ±SEM
		1st	2nd	3rd	4th	5th	6th	
1. Technical parameters of a vertical boom sprayer								
1.1 Spray volume	L/0.16 ha	126	126	133	120	126	133	127.0±1.9
1.2 Spraying time spent (2 workers)	minute/0.16 ha	20	20	21	19	20	21	20.0±0.3
1.3 Amount of insecticide								
1.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	126	126	-	-	-	-	126.0±0.0
1.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	99	90	-	-	95.0±5.0
1.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	189	199	194.0±5.0
1.4 Amount of surfactant	ml/0.16 ha	19	19	20	18	19	20	19.0±0.3
2. Technical parameters of a self-propelled vertical boom sprayer								
2.1 Spray volume	L/0.16 ha	110	120	130	140	120	110	122.0±4.8
2.2 Spraying time spent (2 workers)	minute/0.16 ha	11	12	13	14	12	11	12.0±0.5
2.3 Amount of insecticide								
2.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	110	120	-	-	-	-	115.0±5.0
2.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	98	105	-	-	101.0±4.0
2.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	180	165	173.0±8.0
2.4 Amount of surfactant	ml/0.16 ha	17	18	20	21	18	17	18.0±0.7
3. Technical parameters of a spray lance								
3.1 Spray volume	L/0.16 ha	160	170	175	160	145	175	164.0±4.6
3.2 Spraying time spent (2 workers)	minute/0.16 ha	33	35	36	33	30	36	34.0±0.9
3.3 Amount of insecticide								
3.3.1 emamectin benzoate 1.92% EC	ml/0.16 ha	160	170	-	-	-	-	165.0±5.0
3.3.2 imidacloprid 70% WG	g/0.16 ha	-	-	131	120	-	-	125.0±5.0
3.3.3 fipronil 5% SC	ml/0.16 ha	-	-	-	-	218	262	240.0±22.0
3.4 Amount of surfactant	ml/0.16 ha	24	25	27	24	22	26	25.0±0.7
4. Decreasing technical parameters								
4.1 a vertical boom vs a spray lance								
4.1.1 Spray volume	percent	21.3	25.9	24.0	25.0	13.1	24.0	22.2±1.9
4.1.2 Spraying time spent	percent	39.4	42.9	41.7	42.4	33.3	41.7	40.2±1.5
4.1.3 Insecticide	percent	21.3	25.9	24.4	25.0	13.3	24.0	22.3±1.9
4.1.4 Surfactant	percent	20.8	24.0	25.9	25.0	13.6	23.1	22.1±1.8
4.2 a self-propelled vertical boom vs a spray lance								
4.2.1 Spray volume	percent	31.3	29.4	25.7	12.5	17.2	37.1	25.5±3.7
4.2.2 Spraying time spent	percent	66.7	65.7	63.9	57.6	60.0	69.4	63.9±1.8
4.2.3 Insecticide	percent	31.3	29.4	25.2	12.5	17.4	37.0	25.4±3.7
4.2.4 Surfactant	percent	29.2	28.0	25.9	12.5	18.2	34.6	24.7±3.3

Table 5. Technical cost analysis at an orchid nursery, Samphan district, Nakhon Pathom province, August–September 2019 (1st trial)

Details	Unit	Timing of application						Mean ±SEM
		1st	2nd	3rd	4th	5th	6th	
1. Technical economic analysis of a vertical boom sprayer								
1.1 Worker cost[1/] (2 workers)	Baht/0.16 ha	35	34	39	39	35	41	37.0 ±1.2
1.2 Cost of insecticide								
1.2.1 emamectin benzoate 1.92% EC[2/]	Baht/0.16 ha	72	68	-	-	-	-	70.0 ±2.0
1.2.2 imidacloprid 70% WG[3/]	Baht/0.16 ha	-	-	109	104	-	-	107.0 ±3.0
1.2.3 fipronil 5% SC[4/]	Baht/0.16 ha	-	-	-	-	95	110	103.0 ±8.0
1.3 Cost of surfactant[5/]	Baht/0.16 ha	5	5	6	6	5	6	6.0 ±0.2
Total	Baht/0.16 ha	112	107	154	149	135	157	814
2**. Technical economic analysis of a self-propelled vertical boom sprayer**								
2.1 Worker cost (2 workers)	Baht/hour	24	22	24	26	26	21	24.0 ±0.9
2.2 Cost of insecticide								
2.2.1 emamectin benzoate 1.92% EC	Baht/0.16 ha	78	72	-	-	-	-	75.0 ±3.0
2.2.2 imidacloprid 70% WG	Baht/0.16 ha	-	-	107	116	-	-	111.0 ±4.0
2.2.3 fipronil 5% SC	Baht/0.16 ha	-	-	-	-	111	87	99.0 ±12.0
2.3 Cost of surfactant	Baht/0.16 ha	6	5	6	6	6	5	19.0 ±0.9
Total	Baht/0.16 ha	108	99	137	148	143	113	748
3. Technical economic analysis of a spray lance								
3.1 Worker cost (2 workers)	Baht/hour	60	65	69	62	63	67	64.0 ±1.4
3.2 Cost of insecticide								
3.2.1 emamectin benzoate 1.92% EC	Baht/0.16 ha	93	102	-	-	-	-	97.0 ±4.0
3.2.2 imidacloprid 70% WG	Baht/0.16 ha	-	-	148	132	-	-	140.0 ±8.0
3.2.3 fipronil 5% SC	Baht/0.16 ha	-	-	-	-	131	139	135.0 ±4.0
3.3 Cost of surfactant	Baht/0.16 ha	7	8	8	7	7	8	7.9 ±0.1
Total	Baht/0.16 ha	160	175	225	201	201	214	1,176
4. Decreasing operation cost								
4.1 a vertical boom sprayer vs a spray lance	percent	30.0	38.9	31.6	25.9	32.8	26.6	31.0 ±1.9
4.2 a self-propelled vertical boom sprayer vs a spray lance	percent	46.4	71.0	57.1	35.6	43.0	64.3	52.9 ±5.5

[1/] worker cost = 56 Baht/hour/worker (based on the labour wage for Thai worker = 450 Baht/8 hours)
[2/] emamectin benzoate 1.92% EC = 600 Baht/L,[3/] imidacloprid 70% WG = 1,100 Baht/kg
[4/] fipronil 5% SC = 530 Baht/L, [5/] Surfactant cost (Tension 7) = 300 Baht/L

Table 6. Technical cost analysis at an orchid nursery, Sainoi district, Nonthaburi province, September – October 2019 (2nd trial)

Details	Unit	Timing of application						Mean ±SEM
		1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	
1. Technical economic analysis of a vertical boom sprayer								
1.1 Worker cost[1/] (2 workers)	Baht/0.16 ha	24	23	26	26	24	28	25.0±0.8
1.2 Cost of insecticide								
1.2.1 emamectin benzoate 1.92% EC[2/]	Baht/0.16 ha	78	78	-	-	-	-	78.0±0.0
1.2.2 imidacloprid 70% WG[3/]	Baht/0.16 ha	-	-	119	108	-	-	114.0±6.0
1.2.3 fipronil 5% SC[4/]	Baht/0.16 ha	-	-	-	-	104	109	107.0±3.0
1.3 Cost of surfactant[5/]	Baht/0.16 ha	6	6	6	6	6	6	6.0±0.0
Total	Baht/0.16 ha	108	107	151	140	134	143	783
2. Technical economic analysis of a self-propelled vertical boom sprayer								
2.1 Worker cost (2 workers)	Baht/hour	16	15	16	18	18	14	16.0±0.6
2.2 Cost of insecticide								
2.2.1 emamectin benzoate 1.92% EC	Baht/0.16 ha	68	74	-	-	-	-	71.0±3.0
2.2.2 imidacloprid 70% WG	Baht/0.16 ha	-	-	117	126	-	-	122.0±5.0
2.2.3 fipronil 5% SC	Baht/0.16 ha	-	-	-	-	99	91	95.0±4.0
2.3 Cost of surfactant	Baht/0.16 ha	5	6	6	7	6	5	19.0±0.9
Total	Baht/0.16 ha	89	95	139	151	123	110	707
3. Technical economic analysis of a spray lance								
3.1 Worker cost (2 workers)	Baht/hour	40	44	46	41	43	45	43.0±1.0
3.2 Cost of insecticide								
3.2.1 emamectin benzoate 1.92% EC	Baht/0.16 ha	99	105	-	-	-	-	102.0±3.0
3.2.2 imidacloprid 70% WG	Baht/0.16 ha	-	-	157	144	-	-	151.0±7.0
3.2.3 fipronil 5% SC	Baht/0.16 ha	-	-	-	-	120	144	132.0±12.0
3.3 Cost of surfactant	Baht/0.16 ha	7	8	8	7	7	8	7.9±0.1
Total	Baht/0.16 ha	146	157	211	192	170	197	1,073
4. Decreasing operation cost								
4.1 a vertical boom sprayer vs a spray lance	percent	26.0	31.8	28.4	27.1	21.2	27.4	27.0±1.7
4.2 a self-propelled vertical boom sprayer vs a spray lance	percent	52.8	57.9	47.7	29.3	35.1	60.8	47.3±5.2

[1/] worker cost = 37.5 Baht/hour/worker (based on the labour wage for migrant worker = 300 Baht/8 hours)
[2/] emamectin benzoate 1.92% EC = 620 Baht/L, [3/] imidacloprid 70% WG = 1,200 Baht/kg
[4/] fipronil 5% SC = 550 Baht/L, [5/] Surfactant cost (Tension 7) = 310 Baht/L

Discussion

In this study, the boom sprayers and spray lance produced similar mortality rates on melon thrips in Dendrobium nurseries, in agreement with the results of Wechakit *et al*. (2008) and Punyawattoe *et al*. (2016) who found that lance spraying at 120 L/0.16 ha produced similar mortality of melon thrips as when lance spraying at rates exceeding 160 L/0.16 ha. One possible reason for their result was the boom sprayer provided smaller droplets may achieve better coverage of under-surfaces and inside the inflorescences due to being carried more easily in the air as indicated by Nuyttens *et al*. (2004a), Sánchez-Hermosilla *et al*. (2013), and Llop *et al*. (2015). In addition, effectiveness depends on the worker's skill in handling the spray lance. When using boom sprayers, in contrast, workers only hold or maintain the level of the boom over the target area. Therefore, the efficacy of boom spraying was superior or equal to lance spraying using the same spray volume or less. Moreover, over-application using the spray lance leads to run-off of insecticide to the ground as reported by Sánchez-Hermosilla *et al*. (2013), Llop *et al*. (2016) and Punyawattoe *et al*. (2019).

There were significant differences in technical parameters and operation costs between the application techniques. The spray lance required more water, time, insecticide and surfactant than the boom sprayers. The differences were due to the boom sprayers delivering a lesser spray volume (120 L/0.16 ha), and spraying in fewer runs over a wider swath. The increased in resource efficiency translated to a cost reduction of more than 27%. This result agrees with Punyawattoe *et al*. (2016) and Sampaothong and Punyawattoe (2018) who found that changes to spray application and swath width could reduce operational costs by 22.4–30.4% compared with using the spray lance at 160 L/0.16 ha.

The same insecticide administration rate was used with both boom sprayers, and the lower cost of using a self-propelled boom was due primarily to the differences in swath width and spraying time. Labour costs varied according to whether Thai or migrant workers were employed. However, the lower costs of insecticide when using the booms with migrant workers that balanced the higher wages of Thai workers using spray lances, and the overall operation costs were similar. These experiments showed that the both insecticide efficacy and operational costs could be considerably improved by the application technique. The boom sprayer was an interesting alternative as it was practical in the fields. Although, the boom sprayer required an initial investment cost depending on the quality of the material, and suitable spray lines in the orchid nursery. However, considering spraying time, operational costs and the operational resources consumed such as water consumption) which is concerned the most economical option.

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