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Cost Effectiveness Analysis of Rice Cultivation among Untreated and Treated Pesticide Application in Rice Field, Ubon Ratchathani Province, Thailand

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Abstract

Adverse effects of pesticide and chemical fertilizers, using in all processes of rice cultivation, have been in environment and human, especially in cost for environment improvement and health care. However, little previous study focused on environment improvement including biodiversity of health determinant. The purpose of this study was to compare incremental cost-effectiveness ratio (ICER) between untreated and treated pesticide application in rice field. The study included untreated and treated rice fields in Ubon Ratchathani Province, Northeast of Thailand to study biodiversity in soil. Then, one hundred and seventy farmers were interviewed on the possible soil improvement from processes of rice cultivation. Data analysis included descriptive statistic, sensitivity analysis, and mean difference (MD) between groups. The results showed that mean of cost for soil improvement was 8,412.63±172.37 baht. ICER on untreated sites was higher than treated sites. The findings showed that cost of rice cultivation in untreated site was more effective than that of treated site. Recommendations of this study were to encourage Thai farmers for reducing pesticide application and suggest to the policy maker to promote organic farming campaign along with local and national level.

Keywords: Cost effectiveness analysis; Pesticide; Rice field

1. Introduction

Thailand is a leading exporter with rice that the highest quality of Thai rice is Jasmine rice to the world's market. As of February 2017, rice export of Thailand was projected to amount to some 10.00 million metric tons (TREA, 2017). To gain the highest quality of the rice, processes of rice planting may include application or no application of pesticide. In Thailand, pesticides usually are used in rice field in Thailand for controlling pests. A main constraint of profitable rice production is insect pests. Most crop loss caused by insects can be attributed to the major pest complex. Pests included plant hoppers, leaf hoppers, bugs, and others belonging to orders Lepidoptera, Thysanoptera (rice thrips) and Coleoptera (Ane and Hussian, 2016). As a result of heavy insect pressure, the control of rice pests has relied heavily on insecticides. Although rice yield has improved, overuse and misuse of these insecticides have led to increasing problems of insecticide resistance, resurgence of pests and introduction of new pests, as well as beneficial insects' destruction (Poolprasert and Jongjitvimol, 2014).

Diversity and community structure of the arthropods in rice ecosystem include rice pests, their natural enemies (predators and parasitoids) and other non-rice pest insects that inhabit or visit the vegetation (Thongphak *et al.,* 2012). In organic rice ecosystem, there are 114 species of arthropods, which consisted of including 58 species of spiders, 16 species of predatory insects, 25 species of phytophagous insects, and 15 species of neutral/other insects, in early season crop. Consequently, we collected 109 species of arthropods, which consisted of 50 species of spiders, 19 species of predatory insects, 24 species of phytophagous insects, and 16 species of neutral/other insects, in the late season crop (Zhang *et al.,* 2013).

Moreover, the adverse effects of pesticides to human arise from various circumstances, both direct and indirect human contacts. Pesticides may impact arthropods directly when a part of its habitat or food supply is modified. For example, herbicides may reduce local food, cover, and nesting sites needed by insects, snakes and reptiles. Insecticides also may diminish insect populations fed on by bird or fish species which biodiversity is one important health determinant and effect from pesticide (Mosleh *et al.,* 2003; Larson *et al.,* 2005). These effects can do harm to human health in complex food chain.

Carbofuran (Furadan 3G) is usually applying in Thai rice field but classified in Carbamates group and toxicity in class Ib. The effect of Carbofuran were acute effect to Earthworm (*Draawida willsi,* Michaaelson) (Panda and Sahu, 2004); genotoxic effect by Morphological alteration in sperms (Chauhan, *et. al.,* 2000); effect to Gold fish (*Carassius auratus*) by decreased sheltering, increased horizontal displacements, burst swimming, buccal movements, and antagonistic interactions (Saglio *et. al.,* 2003). Now, it is restricted in Thailand. However, it is still applying in the field from initial surveying.

Previous study (Chaigarun, 2010) showed that rice productions in treated sites were higher than untreated sites. In contrast, biodiversity upper the soil and soil quality in treated site is lower than that in untreated site. (Chaigarun, 2010; Chaigarun *et al.,* 2011). It means the more quality of good soil, the more members of arthopods, and the more quality of environment. The more quality of environment is one of health determinants as good health (Chaigarun, 2010; Chaigarun et al., 2011). However, the study did not focus on cost of soil improvement from pesticide and chemical fertilizer including limitation sample size only 12 farmers (Chaigarun, 2010). Therefore, the present study focused on cost effectiveness analysis of untreated and treated pesticide application, especially in wastage of environment. We studied destroyed soil including biodiversity of underground insects and cost to repair soil that was destroyed from Pesticide and chemical fertilizers. We then analyzed for economy to present alternative method for policy makers. Therefore, this study aimed to compare incremental cost effectiveness ratio (ICER) between untreated and treated with pesticide application in recommended rate.

2. Materials and Methods

This study consisted of two steps. The first one studied biodiversity in soil for untreated and treated rice fields in the wet and dry season in 2017. The second one also interviewed farmers using structural questionnaire for losing cost from pesticide and chemical fertilizer on rice field, Ubon Ratchathani province and establish productivity relationship between rice yields, economic threshold, and biodiversity in soil. Estimates of these were used to calculate incremental cost effectiveness ratio (ICER).

2.1 The first step

Six rice growing areas in Ubon Ratchathani Provinces, Northeastern of Thailand, were selected as experimental sites in the wet and dry season in 2017. Detailed descriptions of the experimental sites were annual rainfall during May to September and were rice mixed with vegetables. The sampling dates were January 10, to April 20, 2017 in dry season and May 10, to August 15, 2017 in wet season

2.1.1 Sampling

The standard manual for testing insecticides on rice fields developed by the International Rice Research Institute was used to collect insects from the six rice fields under two pesticide treatments: Untreated and treated pesticide in recommended rate. A total of 400 insect samples in soil were obtained in this study, taken at weekly intervals. Three sampling points selected randomly in each sampling site were sampled during this study by the use of the hand sorting sampling method. Soil litter arthropods were collected by using a meter square pick-up point sampling method in five centimeter soil depth after the removal of the leaf litter layer. Targeted soil litter arthropods were pulled out the soil with 11cm sharp-pointed forceps and fingers. Each collected individual arthropod was conserved in a sterile plastic bottle filled with 20 ml of 75% ethanol. Each bottle was stored in laboratory, and analyzed separately from others.

The insect samples in individual vials were sorted and counted together with farmers and checked in the laboratory. The arthropods in soil obtained from the samples were identified to species whether possible. They were later grouped into guilds categories analysed (Moran and Southwood, 1982; Heong et al., 1991).

2.1.2 Insecticide application

Carbofuran (Furadan 3G) was used as a granulate to control insect pests in the rice field in the ratio of 5 kg per rai (5kg/1,600m^2).

Carbofuran was recommended to use for control rice insect pests such as gall midge, stem borer, green leafhopper and brown planthoppers.

2.1.3 Site Selection

Six sites were divided into two groups: the first group as untreated pesticide or control group; and the other one as treated site in recommended rate. The first group had used pesticides and stopped to use it more than 5 years, while the latter group had continuously used pesticides for more than 10 years.

2.1.4 Quality control

1) Well-trained sweepers with experience in the method to sweep and identify types of insects.
2) The following factors were equally assigned to all groups of experiment
   - 2.1 Soil type: Silt-loam
   - 2.2 Fertilizer 15: 15:15 (N: P: K)
   - 2.3 Fertilizer rate: 80 kg per 1,600 m^2
   - 2.4 Type of rice cultivation: direct seeding
   - 2.5 Rice variety: Khao Dok Mali 105 (KDML105)
   - 2.6 Size of experimental area: 1,600 m^2
   - 2.7 Cultural practice: Land preparation, Seed germination

2.2 *The second step*

During study experiment in rice field, in the same time, the total of 170 farmers were the 6 farmers at the experimental sites and 164 farmers were samples (see the calculation in below) on other sites in Ubon Ratchathani province. They were interviewed on the treatment costs including the direct and indirect cost from environmental loss. The rice production yield and sales were also collected at the end of the wet and dry season. Finally, the cost effectiveness analysis was expressed in a standard incremental cost effectiveness ratio (ICER).

2.2.1 Population and samples

Population were farmers in Ubon Ratchathani province who planted rice and sprayed pesticide in rice field more than 10 years and appropriate to totally answer the questionnaire 170 farmers. Sample size was calculated from equation (Aroon, 1999) for mean estimation as below

$$n = \frac{z^2 \times \sigma^2}{e^2}$$

n = sample size

Z = 1.96

σ = Variance from cost of soil improve ment equal to 331.85 (pilot study)

e = Error from cost of soil improvement equal to 50 Baht From the formulation, sample size was 169.22

Therefore, sample size was 170 and they were selected by sample random sampling.

2.2.2 Instruments

Interviewed questionnaire about cost of soil improvement that the soil contaminated pesticide and chemical fertilizers. The questionnaire consisted of two parts. The first one was demographic data (6 items). The other one was data about cost of soil improvement. The cost included labor cost, material cost, and capital cost (20 items). Content validity of the questionnaire was proved by three experts with agriculture and pesticide. The final questionnaire was then improved following the experts (IOC =0.85).

2.3 Data analysis

2.3.1 The first step

2.3.1.1 Cost Effective Analysis (CEA)

After collecting arthropods in rice field, then CEA was calculated by Incremental Cost Effectiveness Ratio (ICER) equation as following:

ICER =

$$\frac{\text{Cost}_{\text{untreated site}} - \text{Cost}_{\text{treated site}}}{\text{Biodiversity Index}_{\text{untreated site}} - \text{Biodiversity Index}_{\text{treated site}}}$$

Regarding diversity indices, provided a comprehensive review of indices (Magurran, 1988). There were numerous diversity indices available in the literatures including Simpson's Index (Lu *et al.,* 2007), Margalef Index (Frosini, 2004), Shannon-Wiener index (Clarke and Warwick, 2001; Nagendra, 2002), Brillouin Index (Singh *et al.,* 2005), etc. Taylor examined the discriminant ability of eight diversity measures (Taylor and Williams, 1978). The measures were used by analysis of variance to test for between- site variations in the total annual moth samples (replicated over 4 years) from nine environmentally stable sites in the Rothamsted Insect Survey.

In conclusion, Taylor reported that the transformed Shannon index (*exp H'*) was the best discriminator. Kempton (1979) also looked at the discriminant ability of the numbers of Hill's family. Once again the Rothamsted moth data were employed but on this occasion the sample size was increased to 14 sites each replicated over 7 years. From the above, Kempton summarized in the same ways of Taylor that the degree of discrimination was greater for the transformed versions of the Shannon indices (*exp H'*) than for its untransformed counterparts. Therefore, the indices that were used in this study were:

1) Shannon-Wiener index (H') The formula for calculating the H' is

$$H' = -\Sigma\, pi^{*} \ln pi$$

Where *pi*, the proportional abundance of the *i*th species = (*n*i/N)

In calculation, exp H', the exponential Shannon-Wiener index, was transformed before comparison because of more discriminating abilities. The functional biodiversity indices analyzed using indices computed by EcoSim (Gotelli *et al.,* 2005)-null model software for ecology. Finally, the sensitivity analysis was conducted by changing the values of the possible minimum and maximum of biodiversity index from standard division (*SD*).

2.3.1.1 The second step

Data were analyzed by descriptive statistic as percentage, mean, and standard division and using the statistic on the Duncan's new multiple range test (DMRT) for compare the significant difference.

3. Results and Discussion

3.1 Biodiversity in soil

Before applying carbofuran in the experimental sites, there were 326 selected arthropods in both treated and untreated experimental rice field in the dry season. Beneficial arthropods were also sorted into two guilds as predators (74.23%) and detritivores (25.77%). However, after applying carbofuran, beneficial insects were lower also found in two guilds as predators (21.73%), and ditritivores (18.44%) (Table 1). During sorting Formicidae were recorded by the most predators. Moreover, Table 1 showed arthropod biodiversity in untreated field had increased comparing with that of treated.

3.1.1 Cost for soil improvement causing by soil degradation

Cost for soil improvement causing by soil degradation from pesticide and chemical fertilizer was 8,412.63 ± 172.37 baht per year before wet season but in untreated site is 0 (Zero) baht per year. Methods of soil improvement included manure and green manure (Table 2). Soil quality was destroyed and exploited by chemical substances (Zhao et al., 2011) such as Nitrogen (N), Phosphorus (P) and Potassium (K).

3.1.2 Total cost and effectiveness of untreated and treated sites with recommended rate

Amount of rice from yield on treated sites were higher than amount of that from untreated sites. However, in fact, price of rice from treated sites (12 baht per a kilogram) was much lower than that from untreated sites (16 baht per a kilogram). Moreover, the biodiversity indices in the untreated site were higher than the treated site (Table 2).

Rice production cost including labor, material, and capital cost in the treated sites was higher than that in untreated sites (Figure 1). The proportion of labor cost showed the highest figure in untreated rice field (Figure 1). The reason was that farmers in organic farm took long time to carefully conduct each process of rice planting such as hand weed, golden apple snail control, and bird repelling. In contrast, farmers in treated sites took more short time with spraying many types of pesticides to control herbicides controlling weed and molluscicides controlling golden apple snail. Hence, policy maker should be promoted on organic rice field by using organic fertilizer

After calculating total costs, it was shown that total costs in treated sites were higher than those in untreated sites.

Table 1 Baseline data of arthropod biodiversity in untreated and treated rice field in Ubon Ratchathani province, Thailand
** Analyzing by EcoSim (Gotelli et al., 2005)*

Guilds	Order	Family	Percentage of total individual		Exp. H' Mean ± SD (adjusted)		MD	95% CI of MD
			Untreated site	Treated site	Untreated site*	Treated site*		
Predators	Hymenoptera	Formicidae						
		Myrmicidae						
		Ponnerinae						
	Coleoptera	Carabidae	74.23	21.73	8.4 ± 0.59^{ns} (131)	8.2 ± 0.32^{ns} (104)	0.2	0.13 to 0.48
		Staphylinidae						
	Araneae	Thomicidae						
		Araneidae						
		Tetragnathidae						
Detritivores	Isoptera	Termitidae						
		Macrotermitidae						
	Coleoptera	Scarabaeidae	25.77	18.44	7.3 ± 0.86^{ns} (79)	7.2 ± 0.54^{ns} (62)	0.1	-1.02 to 1.47
		Elateridae						
		Cicindelidae						
	Others	Earth worms						

Table 2 Total cost and effectiveness of untreated and treated sites with recommended rate

Treatment	Wet season		Dry season
Untreated site			
Rice yield (kg/rai)	420		505
Rice yield benefit (baht/rai)	6,270		8,080
Rice production cost (baht)	12,540		16,160
Soil improvement cost for soil degradation (baht)		0	
Biodiversity index (Mean ± SD)	16.03 ± 2.06		23.32 ± 1.64
Total cost	12,540		16,160
Treated site with recommended rate			
Rice yield (kg/rai)	559		694
Rice yield benefit (baht/rai)	6,708		8,328
Rice production cost (baht)	13,416		16,656
Soil improvement cost for soil degradation (baht)	12.86 ± 1.84		18.12 ± 1.91
Biodiversity index (Mean ± SD)		8,412.63 ± 172.37	
Total cost	17,622		20,862

Remark: 1) Price of organic rice grain per 1 kg = 16 baht; conventional rice grain = 12 baht in wet and dry season

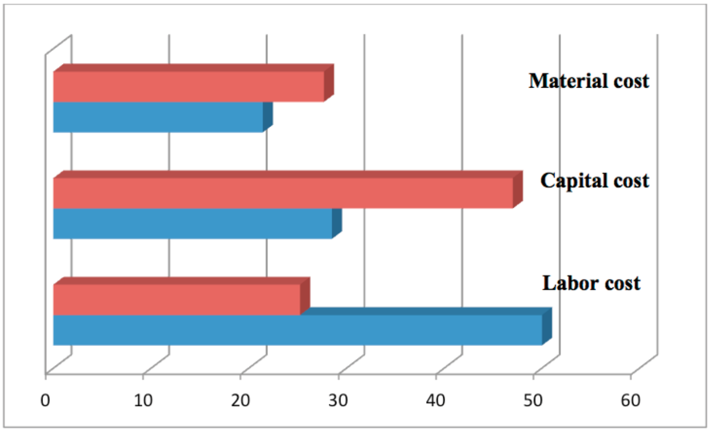

Figure 1 The proportion of labor, material, and capital cost of untreated and treated Sites

3.1.3 The estimated ICER

The ICER of biodiversity index on treated sites was lower than that on untreated sites (Table 3).

Farmers in untreated rice field received more benefit because the negative values of ICER were shown in both wet and dry season (Table 3). It means that both of the biodiversity index and species richness index were decreased after applying pesticide in the experimental field.

3.2 Sensitivity analysis

The aim of sensitivity analysis was to quantify the impact of policy changes or price fluctuations on ICER. The sensitivity analysis in the present study was conducted in only levels for individual level because of limitation of biodiversity indicator in environment. The results of these showed the same tendencies (Table 3).

Table 3 Sensitivity analysis of ICER individual level

Changes due to	**Expected values**
	Incremental cost effectiveness ratio (ICER)
Wet season	
Input	
ICER	-1,603.15
Output (after changing)	
ICER (min,max)	-1,722.71 to -1,499.12
Dry season	
Input	
ICER	-904.23
Output (after changing)	
ICER (min,max)	-953.75 to -859.59

3.3 Discussion

From the result of biodiversity in soil, there were 326 selected arthropods in both treated and untreated experimental rice field in the dry season. Beneficial arthropods were also sorted as predators (74.23%) and detritivores (25.77%). However, after applying carbofuran, in two guilds, beneficial insects were lower as predators (21.73%), and ditritivores (18.44%). Moreover, Formicidae was found from both sites. The findings were related to. They showed that biodiversity of insects above soil at treated sites was lower than that at organic site (Chaigarun et al., 2011). The reason was that carbofuran can kill both pests and beneficial insects. Then, it showed that the number of predators and detritivores was lower including Formicidae. The abundance of dominat spiders declined significantly in the carbofuran treated field. It is concluded that the use of carbofuran is a serious threat to the ground spiders, the important group of biological control agents (Tahir et al., 2011). Moreover, carbofuran (Furadan 3G) highly harmful to earthworm Pheretima javanica, even at low concentrations adversely affect growth and reproduction of the worms (Nofyan et al., 2017). Carbofuran is known to be very toxic to non-target species, and based on its high acute toxicity, its use has been restricted or banned in many countries (Cinar et al., 2015). Carbofuran were problems about increasing rate of soil degradation, decreasing soil fertility and a number of organisms. Pesticide application decreased bacterial population to nearly half of that observed without addition of any toxicant. Magnitude of this decrease was more with addition of carbofuran (Ali et al., 2016).

Tuning to cost for soil improvement, the cost of soil degradation from pesticide and chemical fertilizer was 8,412.63 ± 172.37 baht per rai before wet season. Methods of soil improvement included manure and green manure. Value of ICER was -1,603.15, meaning total cost from treated site was more than that from untreated site but biodiversity index of treated sites was lower than biodiversity index of untreated sites. The reason was that, from finding, the cost of soil improvement from treated site was more than that from untreated site such as more manure and green manure. The manure contains important nutrients such as N, P, K, organic matter, Ca, Mg, etc. It is widely known that green manure and others crop residues improve the soil chemical and biological properties. As an important biological property, soil microbial biomass is used as an ecological attribute to evaluate changes in soil properties by soil use and management (Lopes et al., 2010; Santos et al., 2012). In addition, soil microbial biomass releases enzymes which play important functions in soil processes, such as the decomposition of organic matter (Silva et al., 2012). Thus, soil enzyme activity may be used as an indicator of soil quality due to its control on microbial growth (Burns et al., 2013). For chemical properties, the soil total organic carbon (TOC), available P, exchangeable K and soil pH are important measurements of soil quality because they provide indicators of soil nutrient supplying capacity (Smith and Doran, 1996). Moreover, even the results of treated site was showed more rice yield, benefit and production cost but Chaigarun (2010) in previous study showed health care cost of treated site in both Khon Kaen and Kalasin site were higher than untreated site but benefit cost ratio

(B/C) showed the lower. That mean should be promoted organic rice field such as organic fertilizer for planting.

4. Conclusion and Recommendation

Rice productions in treated sites were higher than untreated sites that showed the same results as previous studies (Haq *et al.,* 2002; Chaigarun, 2010). Though farmers in treated sites gained more production benefits in monetary term. In contrary, when considering both production benefits and soil improvement, the result showed that farmers in untreated sites earned more benefits than treated sites such as the ICER in treated sites were lower than untreated sites. Therefore, the total costs in treated sites were higher than untreated sites. Moreover, the important point is untreated soil and biodiversity index were to environmental friendly.

Overall, the study showed that mean of cost for soil improvement was 8,412.63±172.37 baht. Moreover, the differences between biodiversity index in untreated and treated sites indicated that above ground arthropod diversity can be used as a simple indicator of environmental quality in Environmental health impact assessment (EHIA). However, development environmental index should be study more and accept to Thai society for monitor environmental loss for impact assessment in the future.

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