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Comparative Human-Ecotoxicological Impacts and Willingness to Pay: A Case of Pesticide Transition from Paraquat to Atrazine in Sweet Corn Cultivation in Thailand

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Abstract

Prohibiting the use of paraquat has led to the shift to atrazine application. This has led to changes in human-ecological impacts, but they have not been explored yet. The related monetary values in farmer's perspective also remained unknown. In this study, human toxicity and freshwater ecotoxicity impacts in soil cultivation were evaluated using the USEtox 2.12 model. The willingness to pay (WTP) was employed to explain farmers' values of the impacts of changes. The questionnaire surveys of sweet corn farmers in Lopburi, Saraburi and Nakhon Ratchasima Provinces were ministered by two telephone interviews. The results from 41 respondents revealed that after the ban the average pesticide use of 0.86 ± 0.27 kg active ingredient (a.i.)/rai/year for paraquat was substituted by 0.92 ± 0.43 kg a.i./rai/year for atrazine. The corresponding human toxicities were slightly higher on the paraquat use ($1.33\times10^{-6} \pm 4.21\times10^{-7}$ disability adjusted life years (DALY)/kg emitted) than the atrazine use ($1.30\times10^{-6} \pm 6.21\times10^{-7}$ DALY/kg emitted). On the other hand, the corresponding ecological toxicity were substantially lower on the paraquat use (68.37 ± 21.7 potentially disappeared fraction of species (PDF) m^3 day) than the atrazine use (1262.67 ± 600.83 PDF m^3 day). The average WTP to reduce human and ecological toxicity from the current pesticide use was 216.46 ± 132.28 baht/year and 162.44 ± 111.74 baht/year, respectively. These findings would provide helpful information for relevant authorities to enhance the sustainable management of pesticide uses.

Keywords: Toxicity; Willingness to pay; Paraquat; Atrazine; Sweet corn

1. Introduction

Paraquat, a non-selective herbicide, one of well-known pesticides has been applied in many countries. Several studies have suggested the effects of paraquat, especially on health, acute-chronic and respiratory effects (1). For environmental effects, chemical ingredients in paraquat rapidly and tightly bind to soil particles, making them more immobile and persist higher in soil. Paraquat was widely used in Thailand, including sweet corn cultivation. An interview with 246 cornfield farmers in Thailand showed that 100% paraquat was used (2). Another study pointed that 55.2% of 161 farmers used paraquat in the pre planting phase and 38.1% in the post-emergence phase (3). To protect human health from the threat of paraquat use, fifty countries around the world, including Thailand have officially banned paraquat in 2020 (Kim & Kim, 2019; Laohaudomchok *et al.,* 2021).

Since fewer pesticides are available for use in sweet corn cultivation (4), atrazine becomes one of the alternative pesticides to replace paraquat. This replacement is anticipated to reduce the health impact generating by less toxic chemicals (Department of Agriculture, 2020).

Furthermore, atrazine application demonstrates economic and agronomic benefits in corn field (5). Several studies have contributed the fruitful knowledge on the pesticide uses, however, few studies have focused on the effects of pesticide transitions. Also, the monetary value from pesticide transitions has not been assessed. The cost of human toxicity and ecotoxicity from pesticide transition can be measured by preferences or willingness to pay (WTP) through individuals or public decision whether or not they are willing to pay to reduce, restore or improve the negative impacts (6).

This study aims to assess the human and ecotoxicological impacts transitioning from paraquat to atrazine use in sweet corn cultivation and explore farmers willingness to pay for the impacts of changes in Thailand. The information from the bottom-up aspect will be helpful to policy makers for planning and formulating pesticide change policies to ensure compliance with all stakeholders. The results can also serve as supporting information to establish suitable best management practice in future pesticide management in Thailand.

2. Materials and Methods

2.1 Study area

This study was conducted in three provinces in Thailand: 1) Khao Noi Sub-district of Lam Sonthi District in Lopburi Province, 2) Lam Phaya Klang Sub-district of Muak Lek District in Saraburi Province, and 3) Klangdong and Chanthuek Sub-districts of the Pak Chong District in Nakhon Ratchasima Province. These are the provinces where sweet corn is the main crop and paraquat was used intensely before.

2.2 Population and sample

With the population of 98 enlisted farmers in the National Corn and Sorghum Research Center, this study employed two criteria to select the sample size. Our conditions included: 1) farmers must grow sweet corn more than or equal to three years and started using atrazine in sweet corn cultivation after the paraquat ban, and 2) farmers must be over 18 years. The sample size of 41 organic variety 2 sweet corn farmers met our selection criteria and became our respondents. There were 10 farmers from Khao noi Sub-district, 4 farmers from Lam Phaya Klang Sub-district, 13 farmers from Klangdong Sub-district and 14 farmers from Chanthuek Sub-district. This survey was approved by the Research Ethics Review Committee, Chulalongkorn University, Bangkok, Thailand (No. 060.1/64).

2.3 Data collection

The questionnaire surveys were ministered by two telephone interviews. The first interview was conducted on 15 June 2021. The relevant questions comprised three parts. Part 1 consisted of sweet corn planting information (number of cycles planted per year). Part 2 contained the pesticide use (duration of use and the amount of paraquat use and atrazine use). Part 3 represented the negative health effects questions. The index of item-objective congruence (IOC) was 1, which indicated good content validity of the survey attribute.

The active ingredients, primary data obtained from the first interview, were used as inputs to the USEtox 2.12 model as an emission to agricultural soil (kg/rai/day). The USEtox model (UNEP-SETAC toxicity model) was used in this study for characterizing chemical emissions and demonstrate in human toxicity and freshwater ecotoxicity impacts (7). Pesticide emission into the environment is associated to multi-media, environmental fate, multi-pathway exposure and negative effects in a set of characterization factors (CFs). In this study, active ingredients are converted to mass with the USEtox model to multiply with the characterization factor and calculate impact scores (IS). The impact scores are expressed as disability-adjusted life years (DALY per kg emitted) for health effects and potentially disappeared fraction of species (PDF m^3 d per kg emitted) for ecotoxicity. Toxicological impacts of emitted pesticide were quantified by Eq. (1) (8):

$$IS = \sum_i \sum_x CF_{x,i} \times M_{x,i} \quad (1)$$

where IS is the impact score of pesticide x, $CF_{x,i}$ is the characterization factor of pesticide x released in compartment i, and $M_{x,i}$ is the mass of pesticide x emitted to compartment i. Characterization factor are calculate based on Huijbregts, Struijs (9)

Disability adjusted life year (DALYs) used as a measure of overall human population damage in human toxicity characterization factor (CF_H) at endpoint level for pesticide x (DALY $kg^{-1}_{emitted}$) can be calculated as Eq. (2):

$$CF_{H,x} = IF_{H,x} \times EF_{H,x} \times DF_{H,x} \quad (2)$$

where IF_H is the human intake fraction (kg_{intake} $kg^{-1}{}_{emitted}$) which reflects the fraction of pesticide emission that is taken in by the human via inhalation and ingestion, EF_H is the effect factor (number of cases $kg^{-1}{}_{intake}$) and DF_H is the damage factor (DALY $case^{-1}$) of a pesticide x.

Characterization factor for freshwater ecotoxicity (CF_E) of pesticide x represents potentially disappeared fraction of species (PDF) at endpoint level integrated over the freshwater volume (m^3) and the duration of 1 day per kg emission (PDF m^3 day $kg^{-1}{}_{emitted}$) can be calculated as Eq. (3):

$$CF_{E,x} = FF_{E,x} \times XF_{E,x} \times EF_{E,x} \times DF_{E,x} \quad (3)$$

where FF_E is fate factor (day), XF_E is exposure factor referring to the bioavailable fraction of pesticide in freshwater, EF_E is the effect factor expressing the expression of ecological effects by changes in potentially affected fraction with increased effects (i.e. mortality) caused by changes in pesticide concentrations (PAF m^3 kg^{-1}) and DF_E is damage factor for freshwater ecotoxicity (PDF/PAF).

The second interview was conducted on 23 September 2021 with the same respondents. In this interview, farmers' willingness to pay was the key question. The questionnaire consisted of two parts. Part 1 was designed to obtain information about willingness to pay to reduce health impacts. The health impacts of paraquat-to-atrazine transition calculated by the USEtox model were set as a scenario to ask willingness to pay for various measures to reduce the current health impact. Part 2 was the questions about willingness to pay to reduce the impact on freshwater ecosystems based on the results from the USEtox model. We employed bidding games technique to explore the willingness to pay, followed by dichotomous choice questions (yes or no), and the final open-ended question about maximum farmer's WTP. (Figure 1). The initial bid for both human health and freshwater ecotoxicity impact uses the selling price of 10 kilograms of large sweet corn calculated from the sweet corn planting requirements of the National Corn and Sorghum Research Center 2021.

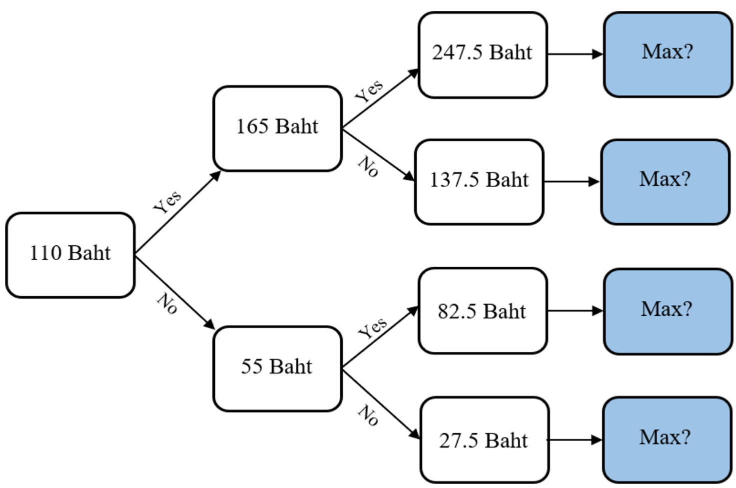

Figure 1. Bidding games for willingness to pay estimation to reduce the health impacts and freshwater ecotoxicity from transitioning paraquat to atrazine in sweet corn cultivation.

3. Results and Discussion

3.1 Pesticide Usage

This study found that 68.29% of farmers had used paraquat more than 5 years, 21.95% for 4-5 years and 9.76% for 3 years. Most (60.97%) farmers reported planting three sweet corn crops per year. The average amount of paraquat used by farmers before the ban was 0.86 ± 0.27 kg a.i./rai/year and substituted by 0.92 ± 0.43 kg a.i./rai/year for atrazine. The active ingredient of paraquat used by farmers was greater than the amount recommended on the package (0.12 - 0.15 kg a.i./rai). The maximum paraquat active ingredient in one crop was found to be approximately 5.5 times higher comparing to the sweet corn cultivation in New Zealand (10).

For atrazine, the active ingredient used by farmers was similar to the amount recommended on the package (0.23 - 0.32 kg a.i./rai). However, the amount of atrazine use in one crop was approximately 1.1 times greater than the sweet corn cultivation in Illinois, Minnesota, and Oregon (11).

In terms of negative health effects, 53.66% of farmers experienced adverse health effects. The self-reported symptoms as a result from the use of pesticides were 59.10% dizziness, 18.18% burning pain, 13.64% headache and others health effects such as chest tightness, stinging nose, sore throat, eye irritation, squeamish and vomiting.

3.2 Human Toxicity and Freshwater Ecotoxicity

The average impact scores for human toxicity potential of paraquat ($1.33\times10^{-6} \pm 4.21\times10^{-7}$ DALY/kg emitted) was slightly higher than atrazine ($1.30\times10^{-6} \pm 6.21\times10^{-7}$ DALY/kg emitted). For freshwater ecotoxicity, atrazine had much higher impact score (1262.67 ± 600.83 PDF m^3 day/kg emitted) than paraquat (68.37 ± 21.7 PDF m^3 day/kg emitted) (Figure 2).

The scenario of this study emphasized emissions to agricultural soil. The most effective mass was found in agricultural soil 99.86%, transferred to freshwater 0.12% and 0.01% were at other media for paraquat. For atrazine emission, 83.31% of the mass remained in soil, 13.74% transferred to freshwater and 2.95% to other media. This proportion indicated that the likelihood of pesticides being persisted or transferred in the environment after soil emissions. Atrazine show the large number of ecotoxicity impact scores because it has been demonstrated to be highly toxic to aquatic organisms, mutagenicity and genotoxicity in aquatic animals.

Health impacts can be divided into two groups depending on the active ingredient used by each farmer. Group 1: Decreased health effects when transitioning from paraquat to atrazine pesticides was 51.22% (the average impact scores of $1.37\times10^{-6} \pm 4.32\times10^{-7}$ DALY/kg paraquat emitted and $8.89\times10^{-7} \pm 2.84\times10^{-7}$ DALY/kg atrazine emitted). Group 2: The transition increased the impact on health (the average impact scores

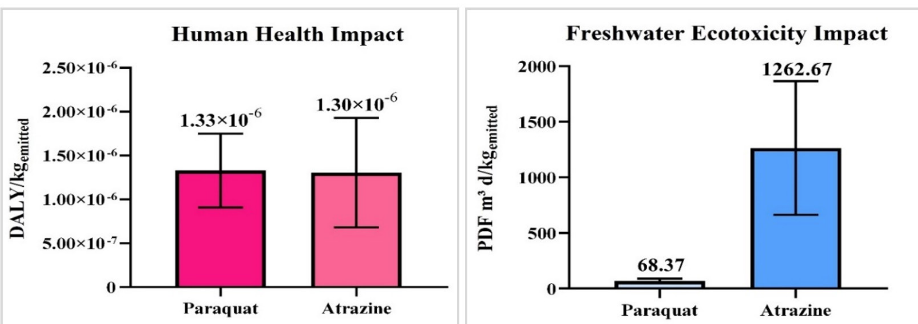

Figure 2. Comparisons of human health and ecotoxicity impact scores between the use of paraquat and atrazine in sweet corn cultivation.

of $1.29\times10^{-6} \pm 4.17\times10^{-7}$ DALY/kg paraquat emitted and $1.74\times10^{-6} \pm 5.79\times10^{-7}$ DALY/kg atrazine emitted).

The USEtox model only considers ingestion (i.e. direct and indirect exposure) and inhalation exposure pathways. The model measures the total carcinogenic and non-carcinogenic effects of humans, in this study only considered non-carcinogenic impact to humans. This tool does not calculate the risk of specific illnesses associated with pesticides. The USEtox model estimates the effects of a single chemical at steady state and does not consider the interaction effect of many chemicals. In order to minimize both health and environmental impacts must be considered concurrently. There is a likelihood of tradeoffs between health and ecotoxicity impact, as it may be difficult to achieve the risk reduction target for both impacts due to other factors such as the pesticide effectiveness and the cost of suitable pesticides to farmers.

3.3 Farmers' willingness to pay

An average value of 216.46 ± 132.28 baht/year (max 500, min 20) were farmers' willingness to pay to reduce health impact from the current pesticide use, with the 87.80% (36 persons). Farmers who were willing to pay did not want the health effects to occur and they can afford the cost. For farmers who were not willing to pay, even if health problems arise, they perceived this issue was out of their responsibility because the legal pesticide is permitted from top-down policy. They will be willing to pay when the health effects are clearly visible.

The average willingness to pay to reduce the ecotoxicity impact from the current pesticide use was 162.44 ± 111.74 baht/year (max 300, min 10), with the 85.37% (35 persons). Farmers who were willing to pay desired to maintain the ecosystem as the need for a shared responsibility because everyone is involved in the use of pesticides. The 33.33% of farmers who were not willing to pay argued that the impact on the ecotoxicity was not imminent and did not directly affect farmers. Another 33.33% claimed that it was not the responsibility of the farmers. Some farmers would like to have their split responsibility up to the amount of atrazine use and will be willing to pay only if the impact is apparent. In this study, farmers also prioritized health over the environment. Farmers' willingness to pay reflects health and environmental values that can be considered in conjunction with the tradeoffs between health and ecotoxicity impacts arising from continued use of pesticides.

4. Conclusion

This study investigated the human toxicity and freshwater ecotoxicity impacts of the conversion of paraquat to atrazine pesticides in sweet corn cultivation, considering scenario in which the active ingredient is sprayed to agricultural soil. Based on the toxicological assessments, paraquat showed slightly greater health effects than atrazine. Paraquat was highly soil-tolerant and less transfer to freshwater than atrazine. Farmers were more likely to be exposed to paraquat from agricultural soils and have long-term health effects. In contrast, the mass of atrazine was more likely to transfer to freshwater ecosystems, resulted in higher ecotoxicity impacts. Our WTP results indicated that farmers valued health 1.3 times over ecotoxicity impacts. This study bridges the toxicological data with economic tools to create understanding and participation at the local level. The information required for the risk assessment and toxicity results obtained from this study help decision-makers understand pesticide behavior. Valuing farmers' impact, reflecting pesticide management policies for sweet corn cultivation in Thailand.

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