Ethion Exposure and Biological Monitoring in Vegetable Farmers

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Objective: *To modify the method of analysis of urinary diethyl phosphate (DEP) in order to determine the relationship between atmospheric ethion concentration and urinary DEP concentration.*
Materials and Method: *A cross-sectional study was conducted by collecting atmospheric ethion in the breathing zone of 28 farmers following the NIOSH 5600 method. Urine samples were also collected to analyze urinary DEP concentrations by a modified method using a Gas Chromatography-Flame Photometric Detector (FPD).*
Results: *The average atmospheric ethion concentration in the breathing zone of farmers was 0.036 $\pm$ 0.018 mg/m^3. The average urinary DEP in pre-shift and post-shift was 0.030 $\pm$ 0.06 and 0.851 $\pm$ 1.80 mg/g of creatinine respectively. The average DEP during work shifts was 0.53 $\pm$ 0.27, and ranged from 0.12 to 1.16 mg/g of creatinine. A high correlation coefficient ($r = 0.645$) was found between atmospheric ethion concentrations and urinary DEP concentrations at $p < 0.001$.*
Conclusion: *The modified method provided a reliable result and the urinary DEP during work shifts was found to be a reliable biomarker of ethion exposure.*

Keywords: *Ethion, Diethyl phosphate, Organophosphate metabolites*

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Thailand is widely known as an agricultural country. Approximately 19.4 million hectares of the country's area is used for cultivation and almost 29.4 million people work in agricultural fields[1]. Thai farmers are at risk of pesticide poisoning due to improper use of personal protective equipment (PPE) and an inadequate knowledge of pesticide toxicity, *e.g.* the use of several types of pesticides mixed together[2]. Ethion is the insecticide in the organophosphate group. An acute effect of exposure is the inhibition of acetyl cholinesterase in the nervous system[3]. The half-life of ethion in the human body is 24 hours. Human exposure to ethion can be assessed by diethyl phosphate (DEP), diethylthiophosphate (DETP) and diethyl dithiophosphate (DEDTP) in urine[3]. Although all these metabolites are not specific for ethion, they are the metabolites of the organophosphate group.

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The methods used for the present analysis of urinary DEP included lyophilization, extraction, derivatization and then analysis using gas-liquid chromatography (GC) with a flame photometric detector (FPD)[4], a GC with a mass spectrometer (MS)[5] or a GC/MS/MS[6]. The modified method used liquid-liquid extraction, derivatization with pentafluorobenzylbromide (PFBBr) and analysis with a GC/FPD. The method for analysis of urinary DEP was modified and used to assess urinary DEP concentrations in 28 vegetable farmers in Wiharndean sub-district, Wiharndean district, Saraburi. The correlation coefficient of atmospheric ethion concentrations and urinary DEP concentration was also determined.

Material and Method

Chemicals and reagents

Ethion 90+%, analytical standard grade and 2, 3, 4, 5, 6- Pentafluorobenzylbromide 99%, were purchased from Sigma-Aldrich, Germany. Diethyl phosphate 99.5%, standard grade was from Supelco, USA. The other reagents were of analytical grades.

Instrumentation

The Hitachi 263-80 gas chromatograph (Hitachi 263-80, Hitachi, Tokyo, Japan) with an OV-17 packed column (2 m x 3 mm ID), equipped with a flame photometric detector (phosphorous mode) and an integrator was used. The carrier gas was nitrogen at a flow-rate of 10 ml/min with a make-up gas of oxygen at 15 ml/min. The GC condition was 225°C isothermal column with 250°C injector and 300°C detector.

Ultrasonic bath. An ultrasonic steri-cleaner, Coax group corporation Ltd., Thailand.

SKC personal air sampling pump (SKC Inc., eighty four, Pa, USA).

Filter/solid sorbent tube-OVS-2 tube, 13-mm quartz, XAD-2, 270 mg/140 mg (SKC 226-58, SKC Inc., Eighty Four, Pa, USA).

Determination of diethyl phosphate (DEP) metabolite in urine

Sample analysis

The 5-ml urine samples were placed in 15-ml glass centrifuge tubes. Then, 30 µl of 106 mg/ml dibutyl phosphate solution (IS) and 4 g of sodium chloride were also added. The solution was acidified with 1 ml, 12 N HCL and 5 ml of acetonitrile/ether (1:1), was used for the extraction of DEP. The tubes were capped, mixed in a vortex for 2 minutes and centrifuged at 2,000 rpm for 5 minutes. After that, 2-ml of the organic phase extract was transferred to another tube and held in an ice bath. From this extraction tube, the residual solvent was discarded and the extraction was repeated with 5 ml of acetonitrile/ether (1:1) and the second 2-ml organic extract was combined with the first portion. A 4-ml sample of the organic extract was evaporated with air blow at room temperature to reduce the volume to 2-ml for derivatization. The 25 µl of pentafluorobenzylbromide (PFBBr) and 30-40 mgs of anhydrous potassium carbonate were added to the tube. The solution was mixed and heated at 60°C for 3 hours in a water bath. The supernatant was transferred to a clean tube and evaporated to dryness with air blow. The samples were reconstituted using 120 microlit of toluene and exactly 2 microlit of the solution was injected into the gas chromatograph with an FPD.

Calibration curve of urinary DEP

Five known concentrations of working standard DEP at 0.0645, 0.129, 0.516, 1.29 and 2.58 microgram/ml in acetonitrile were prepared. The 5-ml pooled normal urine from people not exposed to ethion was placed in 15-ml glass centrifuge tubes. Then, 200 microlit of working DEP standard, 30 microlit dibutyl phosphate (IS) and 4 g of sodium chloride were also added. It was analyzed following the method described above. The peak area ratios of DEP/IS derivatives were plotted against the concentrations of DEP.

Accuracy and precision of the method

The accuracy and precision of the method was determined by analysis of known concentrations of diethyl phosphate (DEP) in urine at 0.0903, 0.516, 1.806 microgram/ml for three replications and for three days. The accuracy and precision was reported for between-day assays in terms of percent recoveries and relative standard deviations.

Detection limit of the method

The detection limit was performed following the National Institute for Occupational Safety and Health (NIOSH) method[7]. The five points of low concentration of urinary DEP ranging from 0.002-0.05 microgram/ml in urine, 0.00258, 0.0129, 0.0258, 0.0387, and 0.0516 microgram/ml were prepared and analyzed as described above. The limit of detection was calculated at three times the standard error of the regression and divided by the slope of the regression.

Application in the field

Subjects

The 28 farmers planted vegetables in Wiharndean sub-district, Wiharndean district, Saraburi, and used ethion insecticides for destroying insects. They planted vegetables in the field for 4-5 years. Each year, they rotated several types of vegetables, corns, Chinese cabbage, and lettuce, etc. They used two types of spraying equipment, boat motor pumps and portable motor pumps with a capacity of approximately 200 liters and 15 liters, respectively.

For use in a boat motor pump, 100-150 ml of ethion was mixed with approximately 200 liters of water in the bilge of the boat. A piece of wood was placed on top of the boat allowing the farmer to sit on the boat and spray the insecticide as shown in Fig. 1. For portable motor pump usage, 40-50 ml of ethion was mixed with approximately 15 liters of water and put into a tank and carried by a farmer while spraying ethion. The present study was reviewed and approved by the Ethics Committee on Human Rights Related to Human Experimentation no. MUPH 2008-157, Mahidol University, Bangkok.

Fig. 1 A farmer spraying ethion using a boat motor pump

Sample collection

Air samples in the breathing zone of farmers spraying ethion insecticide were collected using an OVS-2 tube connected with personal air sampling pumps at a flow rate of 1l/min for one to two hours following the NIOSH 5600 method[5]. After sampling, the OVS-2 tube was packed securely in an ice box for shipment and transferred to a freezer at -20°C until it was analyzed.

Urine samples from farmers were collected twice in small polyethylene containers. Urine samples were collected on the first morning urine on both the day before and after ethion were sprayed. The samples were kept in a refrigerator at -20°C until they were analyzed. The farmers were also interviewed in relation to their general characteristics such as work related factors as well as any health symptoms at the end of work shifts.

Analysis of air samples

Ethion concentrations in the breathing zone of workers were determined by gas chromatography with an FPD detector following the NIOSH 5600 method[8].

Analysis of urine samples

DEP in urine samples together with standard DEP and quality control samples were analyzed as described above. Urinary creatinine concentrations were determined by the kinetic Jaffe'colorimetric method using picric acid[9].

Statistical analysis

The percentage, mean and standard deviations were used for analysis of data. The comparison with urinary diethyl phosphate (DEP) between the two groups was illustrated by an independent t-test. The correlation between atmospheric ethion concentration and urinary diethyl phosphate (DEP) concentrations was illustrated by the Pearson correlation. The comparison between urinary diethyl phosphate (DEP) in pre-shift and post-shift was performed by the Wilcoxson signed rank test. Significance level was set at $p < 0.05$.

Results

General characteristics of subjects

All twenty-eight farmers were male (100%). Their average age was 41.39 $\pm$ 8.68 years old. Their average working experience was 12.2 $\pm$ 8.27 years (Table 1). Fourteen farmers sprayed ethion solution using portable motor pumps and the other 14 farmers sprayed ethion with boat motor pumps. Sample collections were carried out during the three months of the Buddhist lent during which none of the farmers drank alcohol (100%) but 35.7% of these farmers smoked cigarettes. When spraying ethion, none of the farmers was aware of the wind direction and they went into their fields spraying according to their respective convenient directions. After spraying, 53.6% of them immediately took a bath and changed their clothes.

The farmers' exposure to atmospheric ethion

The average exposure to atmospheric ethion concentrations of the 28 farmers was 0.036 ± 0.02 mg/m^3 ranging from 0.009 to 0.071 mg/m^3, which 17.86% of workers exposed to ethion greater than the Threshold Limit Value-Time Weighted Average (TLV-TWA) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) of 0.05 mg/m^3[10]. The atmospheric ethion concentrations from portable motor pump usage (n = 14) and boat motor pump usage (n = 14) were 0.031 ± 0.015 and 0.041 ± 0.018 mg/m^3 respectively. The atmospheric ethion concentrations were not significantly different between the two types of spraying equipment (Table 2).

Determination of urinary DEP in farmers

Calibration curve of urinary DEP

The normal urine spiked with standard DEP and dibutyl phosphate (IS) was extracted, derivatized, and analyzed with a gas chromatography-FPD for five concentrations ranging from 0.05 to 2.58 microgram/ml for three replications. A linear relationship between a peak area ratio of diethyl phosphate derivative/IS derivative and DEP concentrations was found. The

Table 1. General characteristics and working factors of rice farmers

Characteristics	Number (%)
Age (year)	
< 35	6 (21.4)
35-54	20 (71.4)
≥ 55	2 (7.1)
Education	
Primary school	5 (17.9)
Secondary school	9 (32.1)
High school	9 (32.1)
Vocational education	5 (17.9)
Working duration (hours per day)	
≤ 1	15 (53.6)
1-2	13 (46.4)
Working experience (years)	
< 9	13 (46.4)
10-19	8 (28.6)
20-29	5 (17.9)
30-39	2 (7.1)
No. of field (Rai)	
≤ 10	14 (50.0)
11-20	11 (39.3)
21-30	3 (10.7)
Quantity of ethion used (ml/20 lit)	
< 40	4 (14.3)
40-100	24 (85.7)
Spraying equipment	
Portable motor pumps (15 lit)	14 (50.0)
Boat motor pumps (200 lit)	14 (50.0)
Spraying behaviors	
Upward of air flow	-
Convenient	28 (100.0)
Hygienic behavior	
Taking a bath immediately after spraying and changing clothes	15 (53.6)
Cleaning hands and face	8 (28.6)
Not cleaning	5 (17.9)

Table 2. Comparison between atmospheric ethion concentration between portable motor pump usage and boat motor pump usage

Variable	Atmospheric ethion concentrations (mg/m^3) (mean ± SD)	p-value
Portable motor pump usage	0.031 ± 0.015	0.110
Boat motor pump usage	0.041 ± 0.018	

equation of the calibration curve was y = 0.9675x + 0.011; where y = a peak area ratio of diethyl phosphate derivative/IS derivative and x = DEP concentrations. The coefficient of determination, R^2, was 0.9991. The detection limit of DEP in urine was 0.007 microgram/ml[7].

Chromatographic separation

The chromatogram of standard DEP and dibutyl phosphate is shown in Fig. 2A. The diethyl phosphate (DEP) and IS derivative peaks were eluted at the retention times of 2.23 and 4.30 minutes respectively.

Accuracy and precision of the method

The accuracy and precision of the method was reported for between-day assays in Table 3. The recoveries of DEP over the range of 0.09-1.81 microgram/ml ranged from 93.87% to 100.46%. The relative standard deviation ranged from 1.46 to 3.30%.

Urinary DEP in farmers

The urine samples were analyzed using the GC-FPD and the chromatogram showed that the peaks of diethyl phosphate and IS derivatives (internal standard, IS) were separated completely within 7 minutes (Fig. 2B). The concentrations of urinary DEP of the 28 farmers are presented in Table 4. In the present research, concentrations of DEP during-shift

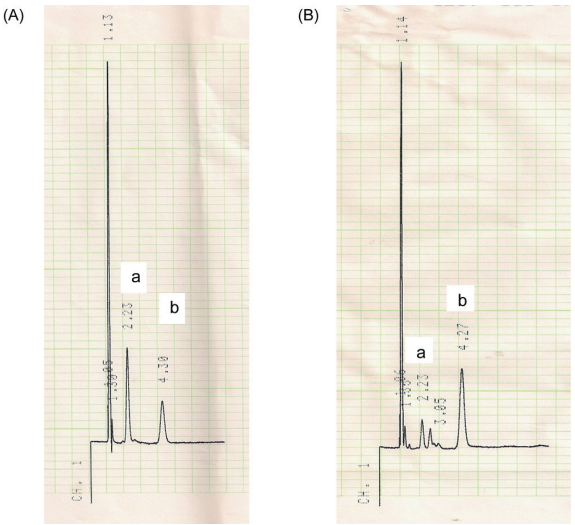

Fig. 2 Chromatogram of (A) standard DEP and dibutyl phosphate (IS) in normal urine and (B) chromatogram of DEP and dibutyl phosphate (IS) in the urine of a farmer exposed to ethion

Table 3. The between day assay for the determination of accuracy and precision of diethyl phosphate (DEP) in urine

Known conc. (microgram/ml)	Analyzed conc. (mean ± SD)	% CV	% average recovery
		Between-day (n = 3)	
0.090	0.084 ± 0.002	3.30	93.87
0.516	0.508 ± 0.007	1.46	98.49
1.806	1.814 ± 0.032	1.79	100.46

CV = coefficient of variation

Table 4. The average concentrations of urinary diethyl phosphate (DEP) metabolite of farmers expressed as mg/g of creatinine

Period of urine sample collection	DEP (mg/g of creatinine) (mean ± SD)	DEP (mg/g of creatinine) (range)	p-value
Pre-shift	0.008 ± 0.01	ND-0.04	<0.001*
Post-shift	0.540 ± 0.27	0.12-1.16	
During shift	0.530 ± 0.27	0.12-1.16	

ND = non detectable
* Significant at $p < 0.05$

were calculated using the post-shift urinary DEP subtracted by the pre-shift urinary DEP concentrations. The average urinary DEP during shift was 0.53 mg/g of creatinine ranging from 0.009 to 0.071 mg/g of creatinine. The urinary DEP of workers using two types of spraying equipment were compared. The urinary DEP for workers using portable motor pumps (n = 14) and boat motor pumps (n = 14) were 0.55 ± 0.34 and 0.53 ± 0.20 mg/g of creatinine respectively, which was not a significant difference (Table 5).

Table 5. The comparison between portable motor pump usage, boat motor pump usage and urinary DEP during workshifts of farmers

Variable	Urinary DEP (mg/g creatinine) (mean ± SD)	p-value
Portable motor pump (15 L)	0.55 ± 0.34	0.987
Boat motor pump (200 L)	0.53 ± 0.20	

The comparison between pre-shift and post-shift urinary DEP in farmers

The Wilcoxon's signed-rank test was used to compare between pre-shift and post-shift urinary DEP concentrations and the results showed that post-shift urinary DEP concentrations were significantly higher than the pre-shift urinary DEP concentrations at $p < 0.001$ (Table 4).

The relationship between general characteristics and urinary DEP during-shift of farmers

A significant relationship was found only for the age of the farmers and their urinary DEP's using the Pearson correlation. The correlation coefficient between the age of the farmers and their urinary DEP during-shift was -0.436 at $p = 0.020$ (Table 6).

The comparison of working factors and urinary DEP during-shift of farmers

The Independence t-test was used to compare the DEP concentrations as well as different working durations, spraying equipment but the results did not find any significant differences.

The comparison of health behavior and urinary DEP during workshifts of farmers

The difference of average urinary DEP concentrations during workshifts was also assessed between farmers who smoked cigarettes and those who did not smoke cigarettes as well as those farmers who both bathed and cleaned their hands and faces immediately after spraying ethion and those farmers who did not bathe and wash their hands and faces

immediately after spraying ethion. Using an independent t-test, the results found that the average urinary DEP was significantly higher for smokers than non-smokers at p = 0.008. In addition, the average urinary DEP in farmers taking a bath immediately after spraying was significantly lower than those not taking a bath immediately after spraying at p = 0.017 (Table 7).

The comparison between signs and symptoms and urinary DEP during workshifts of farmers

The comparison between average urinary DEP concentrations between those workers who developed signs and symptoms and those who did not, was performed by an independent t-test. Farmers who sweated had a significantly lower urinary DEP than those who did not sweat when spraying ethion at p = 0.010 (Table 8).

The relationship between the concentration of ethion in the breathing zone and urinary DEP during workshifts of farmers

The Pearson correlation was used to determine the relationship between concentrations of ethion in the breathing zone (mg/m^3) and the urinary DEP concentration (mg/g of creatinine) during the workshifts of farmers. The correlation coefficient was 0.645 at p < 0.001 (Table 6). The scatter diagram plotted between atmospheric ethion concentrations and urinary DEP concentrations of 28 farmers (n = 28) indicated that atmospheric ethion concentrations had a linear correlation with the urinary DEP concentrations as shown in Fig. 3.

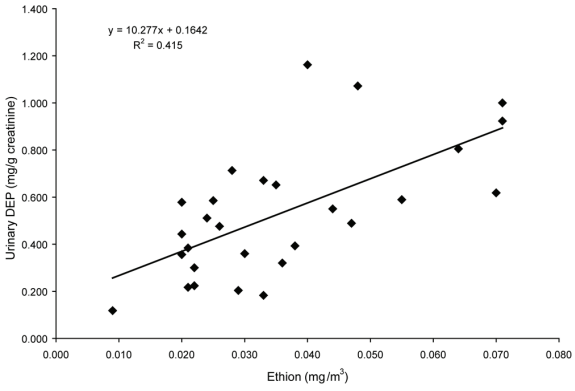

Fig. 3 Scatter diagram between atmospheric ethion concentration (mg/m^3) and the urinary DEP (mg/g of creatinine) excretion of farmers during the work shifts

Table 6. The correlation coefficient between variables and urinary DEP during workshifs of farmers

Variables	Correlation coefficient	p-value
Age of farmers and urinary DEP	-0.436	0.020*
Ethion exposure and urinary DEP	0.645	<0.001*

* Significant at p < 0.05

Table 7. The comparison between health behaviors and urinary DEP during workshifts of farmers

Variable	Urinary DEP (mg/g creatinine) (mean ± SD)	p-value
Cigarette smoking		
No	0.433 ± 0.21	0.008*
Yes	0.710 ± 0.30	
Taking a bath immediately		
No	0.661 ± 0.25	0.017*
Yes	0.420 ± 0.25	
Cleaning hand and face		
No	0.487 ± 0.26	0.175
Yes	0.644 ± 0.30	

* Significant at p < 0.05

Table 8. The comparison between signs and symptoms and urinary DEP during workshifts of farmers

Sign and symptoms	Number (%)	Urinary DEP (mg/g creatinine) (Mean ± SD)	p-value
Vomiting			
No	22 (78.6)	0.471 ± 0.21	0.548
Yes	6 (21.4)	0.549 ± 0.29	
Sweating			
No	23 (82.1)	0.807 ± 0.27	0.010*
Yes	5 (17.9)	0.472 ± 0.24	
Blurred vision			
No	24 (85.7)	0.289 ± 0.08	0.540
Yes	4 (14.3)	0.572 ± 0.27	
Muscular spasm			
No	16 (57.1)	0.566 ± 0.342	0.610
Yes	12 (42.9)	0.507 ± 0.22	
Headache			
No	8 (28.6)	0.580 ± 0.28	0.149
Yes	20 (71.4)	0.413 ± 0.22	

* Significant at p < 0.05

Discussion

Ethion has been widely used in agriculture as an insecticide. The average atmospheric ethion concentration of twenty-eight workers was 0.036 ± 0.017 mg/m^3. Due to wide variation of atmospheric ethion concentrations, five workers were exposed to ethion greater than the TLV-TWA of the ACGIH. The variation of ethion concentrations in the breathing zone among farmers may be due to several factors: 1) the equipment used for spraying, 2) the quantity of ethion used and 3) environmental factors such as wind direction, wind speed, temperature and relative humidity.

The method used for the analysis of urinary DEP was modified from Shafik et al[11], by using liquid-liquid extraction and then derivatization with pentafluorobenzylbromide (PFBBr)[12] and analysis using gas liquid chromatography with an FPD. This method is simple and gives reliable results. The detection limit of DEP in urine was 0.007 microgram/ml. The previous study by Petchuay and co-worker[12] reported that the detection limit of DEP was 3 microgram/l, whereas the Opinion of the Human Biomonitoring Commission of the German Federal Environmental Agency[8] reported a detection limit of 1μg/l. The detection limit of the present study is not as good as the previous method probably due to the packed column used by the present study. The accuracy of the method was satisfactory and similar to the previous methods[12,13].

The diethylphosphate (DEP) metabolite was detected in the urine of twenty-eight workers, ranging from 0.12 to 1.16 mg/g of creatinine. The biological exposure indices (BEI's) for DEP were not available. In comparison to another study undertaken in the USA, it was found that among the general population of the USA a urinary DEP of 5-10 μg/g of creatinine was detected[14]. The non-occupational setting in agricultural fields detected a urinary DEP ranging from non-detectable (ND) to 48.57 μg/g of creatinine[15]. In the present study, urine samples were collected twice. The first samples were collected from the first-morning urinations before spraying ethion (pre-shift); their DEP's ranging from ND to 0.044 mg/g of creatinine, whereas the second samples were collected on the first-morning urination of the next day after spraying ethion (post-shift); their DEP's ranging from 0.12 to 1.16 mg/g of creatinine. From these results, DEP was found in urine at pre-shift because DEP was not a specific metabolite of ethion exposure. Farmers may be exposed to other organophosphate insecticides from environmental contamination, which were still in the body. The general population may be exposed to small amounts of ethion by eating or drinking contaminated food and vegetables. In order to eliminate exposure from other sources prior to spraying ethion, the concentrations of DEP during shift, were calculated by subtracting the DEP at post-shift with the DEP at pre-shift.

The average urinary DEP in farmers who smoked cigarettes was significantly higher than those farmers who did not smoke. Cigarette smoking is known to induce hepatic cytochrome P-450 enzymes in humans[15]. This enzyme catalyses and changes ethion into ethion monoxon, which probably leads to a higher urinary DEP concentration. The average urinary DEP in farmers who bathed immediately after spraying was significantly lower than those who did not immediately bathe after spraying. The three pathways to exposure to ethion are inhalation, oral exposure and dermal exposure[3]. Dermal absorption of ethion has also been measured in humans. Wojeck et al studied workers' exposure to ethion in Florida citrus and found that dermal exposure was the highest of these pathways[16].

In comparing the two types of spraying equipment, the portable motor pump and the boat motor pump, the results showed that farmers who sprayed with a portable motor pump had a slightly lower atmospheric ethion concentration than those who sprayed with boat motor pumps. The farmers using a boat motor pump had a slightly higher urinary DEP than those with a portable motor pump, probably because farmers who used a boat motor pump had to sit or stand in their boats while spraying, which increased their chances of being exposed to the ethion aerosol. The quantity of ethion used (200 lit) for boat spraying for each shift was greater than that used (15 lit) for a portable motor pump. Most farmers needed to be immersed in the water to push their boats before and after spraying ethion. During spraying, ethion may have contaminated the water next to the vegetable crop. The duration of boat spraying is generally longer than that of portable motor pump spraying.

The correlation between ethion concentrations in the breathing zone and the urinary DEP of farmers was significant by the Pearson correlation (correlation coefficient, $r = 0.645$, $p < 0.001$). Nigg et al detected ethion in the saliva of pest control applicators. The urinary ethion metabolite was also detected in the worker's urine. The correlation between urinary ethion metabolite and saliva ethion was 0.55 at $p = 0.0001$[4]. The concentrations of DEP used for the calculation of

the correlation coefficient with ethion in the breathing zone were the DEP's from spraying of ethion on that day. The correlation of atmospheric ethion concentrations and urinary DEP concentrations was high, 0.645. Therefore, urinary DEP concentrations can be used as biomarker of ethion exposure.

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Potential conflicts of interest

None.

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ปริมาณการสัมผัสสารอีไทออนและการตรวจดัชนีทางชีวภาพในเกษตรกรชาวสวนผัก

พรพิมล กองทิพย์, ศิรินทร์นภา ช้างเฟื่อง, วิทยา อยู่สุข, สุทธินันท์ ฉันท์ธนกุล, ดุสิต สุจิรารัตน์

วัตถุประสงค์: *เพื่อปรับปรุงวิธีการวิเคราะห์ปริมาณสารไดเอตทิลฟอสเฟตเพื่อหาความสัมพันธ์ระหว่างความเข้มข้นของอีไทออนในบรรยากาศ และความเข้มข้นสารไดเอตทิลฟอสเฟตในปัสสาวะ*

วัสดุและวิธีการ: *เป็นการสำรวจภาคตัดขวางโดยการเก็บตัวอย่างอีไทออนในบรรยากาศที่บริเวณหายใจของชาวสวน 28 คน ตามวิธีการของ NIOSH method 5600 และทำการเก็บปัสสาวะของเกษตรกรและวิเคราะห์หาไดเอตทิลฟอสเฟตด้วยวิธีที่พัฒนาขึ้นโดยใช้ก๊าซโครมาโตรกราฟฟี่-เฟลมโฟโตเมตริกดีเทคเตอร์ (FPD)*

ผลการศึกษา: *ค่าเฉลี่ยของอีไทออนในบรรยากาศบริเวณหายใจ มีค่า 0.036 ± 0.018 มิลลิกรัม/ลูกบาศก์เมตร ค่าเฉลี่ยความเข้มข้นไดเอตทิลฟอสเฟตในปัสสาวะก่อนและหลังการรับสัมผัสเท่ากับ 0.030 ± 0.06 และ 0.851 ± 1.80 มิลลิกรัม/กรัมครีอะตินินตามลำดับ ค่าเฉลี่ยระหว่างการรับสัมผัสเป็น 0.53 ± 0.27 มีค่าอยู่ระหว่าง 0.12 ถึง 1.16 มิลลิกรัม/กรัมครีอะตินิน พบค่าสัมประสิทธิ์สหสัมพันธ์สูง ($r = 0.645$) ระหว่างความเข้มข้นอีไทออนในบรรยากาศและความเข้มข้นของไดเอตทิลฟอสเฟตในปัสสาวะ ที่ $p < 0.001$*

สรุป: *วิธีวิเคราะห์ที่พัฒนาขึ้นให้ผลที่เชื่อถือได้และไดเอตทิลฟอสเฟตในปัสสาวะระหว่างการทำงานเป็นดัชนีชี้วัดทางชีวภาพที่เชื่อถือได้สำหรับการรับสัมผัสอีไทออน*