Water-mediated Discharge of Pesticides from a Sloped Lychee Orchard, N-Thailand

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Abstract

Fruit cropping is considered to be a sustainable alternative to annual field crops in the mountainous regions of northern Thailand because permanent cultures are less prone to erosion, but little is known about pesticide discharge from Thai fruit orchards. The objective of our study was to investigate water-mediated transport of agrochemicals from a sloped lychee plantation into ground and surface water. Therefore, we installed suction lysimeters, wick lysimeters (both in 55 cm soil depth) and surface runoff collectors in a 10-year-old orchard with grass-covered soil. Then, water and pesticide fluxes were monitored for 50 days after repeated manual applications of organochlorine and organophosphorous insecticides typically used in lychee production (simultaneous applications of 6 different compounds every 10 days). The regular treatments built up a pool of dischargable pesticides so that, despite exceptionally low precipitation (22.6% of rain that fell in same period in the year preceding our study), more than 200 mg ha\textsuperscript{-1} was washed off (malathion; leaching + runoff). Although this is only 4.8 \texttimes 10\textsuperscript{-3}% of one application, peak concentrations were as high as 3200 µg l\textsuperscript{-1} in runoff (malathion) and 18 µg l\textsuperscript{-1} in leachate (dimethoate). These concentrations clearly exceeded toxicity levels tabulated for aquatic species (up to 1700fold, malathion), so that we recommend an event-triggered monitoring program for the creek adjacent to our plot.

Introduction

Thai lychee production requires high doses of insecticides and fungicides. During fruit ripening, these agents are applied in 10-day intervals. Such repeated use maintains a pool of readily available pesticides prone to surface runoff or leaching. Therefore, despite of the relatively rapid dissipation of pesticides from tropical ecosystems (1), these substances can have negative effects on adjacent aquatic populations (2). Because high temperatures promote biological uptake and metabolism of xenobiotics, tropical aquatic ecosystems are particularly sensitive to pesticide input and have been suggested as priority areas for toxicological research (3). Discharge of pesticides from the treated area by flowing water can lead to diffuse inputs into surface waters for weeks after application, either directly by runoff (4) or indirectly when leachate drains into surface water (5). Wauchope (4) and Flury (5) reported that leaching and surface runoff may each result in a loss of ca. 0.5 – 1% (max: 5%) of the applied amount.

In a preceding study, we elucidated the variation of water flux in a northern Thai lychee orchard and demonstrated that pesticide concentrations in leachate peak after the first rainfall following the treatment (6). Because a monsoonal rainstorm shortly after application is more likely to occur the more frequently the spraying is repeated, the local agricultural practice bears the risk of
substantial pesticide losses. This is true both for leaching and surface runoff; the latter, however, has not yet been investigated in our research area. Thus, to further contribute to an evaluation of the sustainability of fruit cropping in northern Thailand, the objective of our work was to measure simultaneously leaching and surface runoff of repeatedly applied pesticides.

Materials and Methods

Experimental Site. We conducted our experiment on a lychee orchard in northern Thailand (18°53’ N, 98°52’E). Due to former use for rice cultivation some decades ago, the slope still is slightly terraced so that relatively steep “steps” (microslopes) alternate with more or less even surfaces (microplains); the overall inclination is ca. 15° (Figure 1). The elevation is 820 m above sea level, and a creek passes the plot further downslope on 780 m. Mean annual precipitation is 1600 mm with distinct dry (November to April) and wet seasons (May to October). The 10 to 15-year-old trees are about 2.5 m high and planted in a grid of 10 by 10 meters; the interspace is covered with grass and herbs that are mown fortnightly with a motorised scythe. The soils of our study area are fine, kaolinitic thermic Hapludults (6, 7).

Sampling design and application of pesticides. On the research site, 2 soil pits were equipped with glass lysimeters with adjustable vacuum (suction plates, borosilicate glass; Ø 90 mm; ecoTech, Bonn with suction control system SCS8, UMS, München) at the B1–B2 horizon transition (55 cm; pits SPL1 and SPL2 in Figure 1). The suction plates were connected to an online solid phase extraction system described earlier (6). In a third pit (WLY in Figure 1), we inserted 3 wick lysimeters (1) in the same depth. Each of the three pits was equipped with a surface runoff collector (Gerlach trough, (8); length: 2.5 m). Precipitation amounts were provided by Klaus Spohrer, University of Hohenheim, who operated a weather station on the orchard. From 06/19 to 07/29/2002, we carried out five consecutive applications of pesticides (10-day intervals; sampling cycles SC 1–5). Each time, six insecticides (one combined “spraying cocktail” of commercially available formulations) were sprayed directly onto the soil surface of the experimental plot with a manual backpack sprayer. The active ingredients were: chlorpyrifos, dimethoate, endosulfan (α and β isomers), malathion, and mevinphos. The application rates were

Figure 1: Map of plot and experimental setup. (a) top view, (b) cross-section.
ca. 2 (mevinphos) to 6 kg ha\(^{-1}\) (endosulfan, chlorpyrifos, Table 1). Both the substances and the repeated applications are common in the studied production system. However, the dose we applied was 2 – 5 times higher. Furthermore, the substances are usually applied as single components and not simultaneously. On day 1, 3, 5, 7 and 10 after each application the solid phase extraction cartridges were removed from the soil solution sampling device, and surface runoff and leachate from the wick lysimeters (if present) were collected. The sampling on day 10 was followed by the subsequent application. All samples were immediately put on ice and transported to the laboratory within 2 hours on normal sampling days or within 5 hours on application days. Further processing was done as described earlier; pesticide concentrations were determined by GLC/EI-MS measurements (6).

**Results and Discussion**

The total fraction of precipitation that leached into the samplers in 55 cm depth was 7.8 ± 1.5 % for the wick lysimeters and 77.7 ± 15.1 % for the suction plates (mean and standard error). This reflects the fact that the wick lysimeters only collect saturated flow, while suction plates also account for unsaturated flow (matrix flow and fingering). It is known that tropical clayey soils often form micro-aggregates, whose hydraulic conductivities are far below average rates of precipitation. Thus, intra-aggregate bypass flow may evolve even if the soil is not yet saturated with water (10), which may be the reason why the suction plates delivered water even after minor precipitation events. Pesticides were detected in several samples from the automatic soil solution sampling device (most frequently endosulfan, data not shown). However, due to unforeseeably low rainfall amount in the study period (22.6% of previous year, not shown) and thus very small sample volumes, it was not possible to quantify these pesticides reliably, so that no further results on leachate collected by suction plates are presented here. Contrastingly, all samples from the surface runoff collectors and wick lysimeters contained pesticides in sufficient amounts for quantification (Table 1; no detection of mevinphos in leachate).

Generally, the concentrations of polar pesticides in surface runoff (mevinphos, dimethoate, and malathion) were 10 to 100 times higher than for the unpolar pesticides (endosulfan and chlorpyrifos; Table 1). For the individual pesticides, the concentrations in surface runoff were 1 (endosulfan, chlorpyrifos) to 3 (malathion, dimethoate) orders of magnitude higher in surface runoff than in soil percolate (not shown). However, due to the higher relative sample volumes collected by the wick lysimeters (as compared to the surface runoff collectors) total discharge in

### Table 1

<table>
<thead>
<tr>
<th>Substance</th>
<th>Appl. rate kg ha(^{-1})</th>
<th>— Cum flux WLY (mg ha(^{-1}))</th>
<th>— Cum flux SRC (mg ha(^{-1}))</th>
<th>Conc(\text{max}) (SRC) (µg l(^{-1}))</th>
<th>Effect conc. O. mykiss (µg l(^{-1}))</th>
<th>Effect conc. D. magna (µg l(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endosulfan-α</td>
<td>4.71 (0.18)</td>
<td>130 (7.8)</td>
<td>2.8 (10^3)</td>
<td>1.4 (0.9)</td>
<td>2.9 (10^5)</td>
<td>15.1</td>
</tr>
<tr>
<td>Endosulfan-β</td>
<td>2.33 (0.09)</td>
<td>67 (4.1)</td>
<td>2.9 (10^3)</td>
<td>4.6 (3.1)</td>
<td>2.0 (10^4)</td>
<td>62.2</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>6.42 (0.25)</td>
<td>52 (3.8)</td>
<td>8.1 (10^4)</td>
<td>1.6 (1.0)</td>
<td>2.4 (10^5)</td>
<td>29.9</td>
</tr>
<tr>
<td>Malathion</td>
<td>4.23 (0.15)</td>
<td>57 (5.4)</td>
<td>1.3 (10^3)</td>
<td>150 (120)</td>
<td>3.5 (10^3)</td>
<td>3164</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>4.45 (0.17)</td>
<td>150 (74.0)</td>
<td>3.3 (10^3)</td>
<td>75 (55)</td>
<td>1.7 (10^3)</td>
<td>1502</td>
</tr>
<tr>
<td>Mevinphos</td>
<td>1.87 (0.08)</td>
<td>n.d.</td>
<td>19 (15)</td>
<td>1.0 (10^3)</td>
<td>779</td>
<td>11.9</td>
</tr>
</tbody>
</table>
soil solution was equal to discharge via surface runoff (polar pesticides except mevinphos) or even higher (unpolar pesticides; Table 1). Although total discharge seemed to be negligibly small, surface runoff concentrations of all pesticides exceeded tabulated effect concentrations for aquatic organisms so that toxic effects are to be expected after runoff events (Table 1). This is especially relevant because lychee production is the dominating form of land-use in the studied catchment: Therefore, pesticide treatments are similar throughout the study area and surface runoff from individual plots will be less diluted by uncontaminated river water than in watersheds with a more diverse pattern land-use (comp. (2)).

Conclusions

In all samples from surface runoff collectors and wick lysimeters pesticides were detected. Therefore, we conclude that both surface runoff and leaching are relevant pathways of pesticide discharge from our experimental plot. Total exports of pesticides are much smaller than reported in literature, which might be caused by the lack of heavy rainstorms during our field campaign. Because our experiment was designed to study pesticide translocation on the profile scale, we cannot tell how long the actual travel distances of surface runoff is nor do we know whether leachate drains into the river before pesticides have dissipated from the soil solution. Nevertheless, simple comparisons of concentrations measured in our experiment with tabulated toxicity values indicate that peak input of pesticides from our plot into the nearby creek might be sufficient to cause adverse effects on the river fauna. Therefore, we suggest a high resolution, event-triggered measurement of pesticide concentrations in river water for further assessments of the environmental impact of lychee cropping in northern Thailand.

References