Sustainable Agriculture: Soil treatment with Insecticide Acephate Causes Contamination of Subsoils

By

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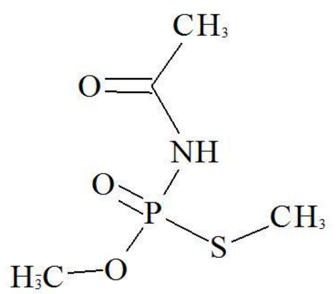
Introduction

In Malaysia and many other tropical countries, pesticides are used intensively in vegetable cultivation. The vegetables are cultivated continuously throughout the year resulting in the high incidence of proliferation of pests in soils. Conducive climate also encourages widespread pests and diseases in the whole agriculture eco-system. In addition, pathogens may also enter soil through the use of untreated chicken manure as fertilizer. Good agricultural practice, such as observing a fallow period between planting seasons, is usually not followed as most farmers have limited land.

To minimize losses due to pathogenic fungi and insects, preventive treatments such soil drenching are carried out in which pesticides are applied to soils at high rates and using large volumes of spraying solutions, after a vegetable crop has been harvested. This practice can cause increased risk of pesticide contamination of soil and water, and pesticide accumulation in the soil resulting in toxicity to non-target organisms. Furthermore, if the pesticides persist for a prolonged time in soil, they may be taken up by new crops.

Many studies on pesticide in the humid tropic soils report rapid dissipation than observed in colder climates. Half-lives (time required for chemicals to degrade by 50%) of less than 20 days were reported for various pesticides in a Brazilian, Malaysian and Thailand soils. Rapid dissipation is attributed to fast microbial degradation, photo-degradation and volatilization. The high precipitation rates in the tropics may accelerate leaching and surface run-off.

One of the common insecticides used in agriculture is acephate (see chemical structure below). Acephate is used to control pests in vegetables and soils. Acephate is hydrophilic with a high water solubility and correspondingly low adsorption to soils resulting in high acephate mobility in soils. The primary degradation product of acephate is methamidophos which itself is an insecticide and generally found at less than 10% of acephate levels. Methamidophos is also very soluble in water.



The aim of the present investigation was to quantify the dissipation kinetics of acephate and to evaluate the formation of their primary metabolites in three representative tropical field soils of Sarawak after soil drenching. In addition, vertical distribution of the pesticides and metabolites in soils was monitored to evaluate pesticide leaching in freshly tilled soil.

Different vegetable planting systems commonly practised in Malaysia

Soils Properties

The experiments were conducted at three sites, namely, Balai Ringin, Tarat and Semongok in Sarawak. All soils were acidic with high clay contents in the subsoils. The organic carbon contents of the topsoils were all less than 1.5%. The subsoils were relatively high in carbon except for the Balai Ringin soil. The clay fraction was dominated by kaolinite and a vermiculitic phase. In addition, the less weathered Tarat soil contained illite.

Experiment

The pesticide treatments were applied at the Balai Ringin, Tarat and Semongok sites, respectively. All vegetations were removed from the plots and the top 20 cm of soil was ploughed manually using a hoe following farmers' practice one week before spraying. Fifteen litres of diluted acephate solutions were sprayed evenly onto the soil using a knapsack sprayer. Buffer strips of 1.0 m were planted with maize to prevent pesticide spray drift.

Soil sampling and pesticide analysis

Soils were sampled at different depths for a period of 98 days for pesticide residue analysis.

Pesticides are extracted from soil samples with solvent in a shaker (right) and water is removed using separating funnel.

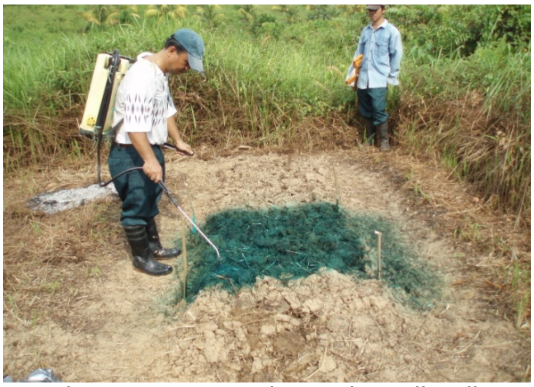
Highly sensitive and precise instruments such as gas chromatograph are used for pesticide detection

Climate

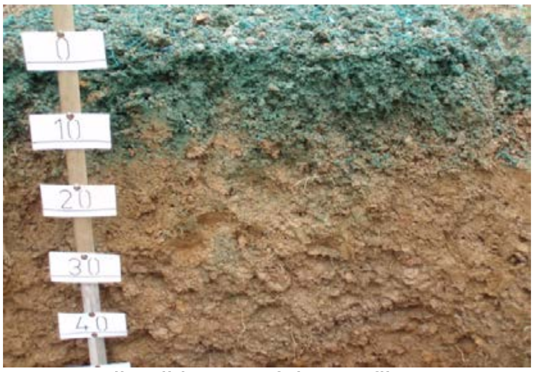
The mean air-surface temperatures at the experimental sites were in the range of 23.8-28.9^{o}C. The precipitations recorded were between 79 mm and 654 mm. Precipitation intensities were very variable with highest intensities of 120 mm d^{-1}. Sunshine hours differed from 2.5 to 6.7 h between the sites.

Dye tracer study

The blue dye was observed down to 1 m. The dye could be seen at all soil layers of the profile, both horizontally and vertically. The dye was evenly distributed in the A horizon (about 15 cm), but only found in cracks, root channels, earth worm burrows, and in other macropores of the B and C horizons. Some larger stained pores, probably former tree roots (> 1 cm diameter), were seen stretching from the A horizon to a depth of 1 m. The estimated soil surfaces covered by the blue dye were 1-5% in the B and C horizons. The diameters of most stained macropores ranged from 1-2 mm, although a few wider macropores were observed.



Acephate was sprayed onto the soil Soil was removed at side using the hoe



Excess soils were removed from the hole Dye is seen at all soil layers of the profile

Pesticide degradation and distribution

The concentrations of acephate in the 0-10 cm soil depth at day 0 were 5-6 times higher for Tarat and Semongok soils compared to the Balai Ringin soil. Acephate concentrations in Tarat and Semongok soils declined very quickly (97-98.5% dissipation at day 2) compared with the Balai Ringin soil (40% dissipation, day 2). Acephate concentrations were not detected in the Balai Ringin soil from 21 days compared with 7 days for the Tarat and Semongok soils.

In subsoils, acephate was present in concentrations between 0.01 and 2.3 mg kg^{-1}. Acephate was detected in subsoils within 2 h after application. The highest subsoil concentrations were observed in the Tarat and Semongok soils at 10-20 cm which also had the highest top soil concentrations. Similarly these two soils which showed fast dissipation of acephate in the topsoil also showed fast dissipation in the subsoil; acephate had disappeared completely after 7 and 4 days in the Tarat and Semongok subsoils while it took 17 days in the Balai Ringin soil which received less precipitation than the Tarat and Semongok profiles. The half-lives of acephate were 2.6, 0.7 and 0.3 days for the Balai Ringin, Tarat and Semongok soils, respectively.

Methamidophos was detected in the top- and subsoils of all profiles. Methamidophos concentrations in top soils were relatively low (0.03-0.95 mg kg^{-1}) compared with the concentrations of the parent compound. Methamidophos concentrations found in the Tarat topsoil on day 0 were 2-4 times higher than in the Semongok and Balai Ringin soils. Methamidophos could be detected at up to 50 cm depth in the Balai Ringin and Tarat soils on day 0 compared to 30 cm in the Semongok soil. As for the parent compound, methamidophos disappeared 2-5 times faster in the Tarat and Semongok soils compared with the Balai Ringin soil where it could no more be detected after 10 days. Neither acephate nor methamidophos were detected at any depth in the control plots.

Photodegradation and volatilization

The mean air surface temperature on day 0 at Balai Ringin was higher (28^{o}C) when compared to the Tarat (26^{o}C) and Semongok (25.2^{o}C) soils. In addition, as spraying was carried out at 11:00, 10:00 and 09:00 hour at Balai Ringin, Tarat and Semongok respectively, the intensity of solar radiation at the three experimental sites was likely to be highest at Balai Ringin and lowest at Semongok. Furthermore, the number of hours with sunshine on day 0 differed greatly at the three experimental sites with 6.7, 1.5 and 2.6 h for Balai Ringin, Tarat, and Semongok, respectively.

Higher air temperature and intensity of solar radiation resulted in up to 5 times lower initial acephate (5.4 mg kg^{-1}) concentrations in the top layer of the Balai Ringin soil when compared to the Tarat and Semongok soils, which had initial concentrations of acephate of 28.1-31 mg kg^{-1}. Many pesticides are susceptible to photo-degradation and volatilization. In addition volatilization losses increase with increasing temperature and relative humidity, which are typically around 25-28^{o}C and higher than 80% for Sarawak. Acephate has medium vapour pressures of 0.23 mPa and is but light sensitive. Volatilization losses of acephate are low due to high aqueous solubility of acephate and its medium vapour pressure.

Pesticide migration and leaching

The amount of precipitation and its distribution over time differed at the three experimental sites. At Balai Ringin, only 3 mm of precipitation was recorded from day 0 to 16, followed by 22.5 mm at day 17. On the contrary, high rainfall occurred close to day 0 at Tarat (day 2, 55 mm) and Semongok (day 1, 61 mm), when acephate concentrations were at their highest. Despite heavy rainfall at Tarat and Semongok, no substantial concentration of acephate was detected in the subsoils down to 50 cm. Acephate and methamidophos are highly soluble compounds which are weakly sorbed in soil and hence both compounds are prone to leaching. The rapid dissipation and the low subsoil concentrations of acephate and methamidophos in the Tarat and Semongok profiles can be partially attributed to preferential flow transport.

Small amounts of acephate and methamidophos were detected in the subsoils only a few hours after the high volume pesticide application corresponding to 1.4 mm of precipitation. Transport via macropore flow paths may have caused this fast leaching to subsoils. All top soils had high moisture contents during pesticide application and this may have induced macropore flow, even though ponding infiltration did not take place. In addition, tilling using a hoe which is the usual farmers' practice may create cracks and pores especially in the top soil which could further facilitate pesticide migration in solution or as sorbed to particles.

The more rapid disappearance of acephate in the Tarat and Semongok top and subsoils compared with the Balai Ringin soil may also be attributed to higher microbial activity caused by higher contents of soil organic matter and the addition of easily degraded plant organic matter. The Balai Ringin soil had been under continuous cultivation for a long period while the two other soils had a significant grass vegetation cover before initiation of the experiment. This means that higher amounts of plant debris were added to the Tarat and Semongok soils which may have caused a higher microbial activity and hence faster degradation.

The amount of acephate applied to the soils on day 0 was 5.2 g m^{-2}. The calculated amounts of acephate detected in the 0 – 50 cm depth of the Balai Ringin, Tarat, and Semongok soils at day 0 were 1.1, 5.4 and 6.0 g, respectively. The corresponding amounts of methamidophos at day 0 were 0.05, 0.2, 0.1 g, respectively. This mass balance again demonstrates the substantial photodegradation/volatilization (> 70%) taking place at the Balai Ringin site compared with the two other sites.

Half-lives of acephate in soils

The half-lives of acephate in the Balai Ringin, Tarat and Semongok soils were 2.6, 0.7 and 0.3 days, respectively. The longer half-lives found in laboratory studies compared with field studies further indicates that the fast dissipation seen in the field may be attributed to mainly preferential flow transport.

Conclusion

Acephate and its primary metabolite methamidophos were found in subsoils at maximum depths examined (50 cm) and at the earliest sampling time (2h) after pesticide application. Very fast dissipation of acephate and methamidophos was attributed to preferential flow transport by macropore flow activated due to the high moisture contents of the soil materials and the presence of many conducting macropores, which could be followed from below the A horizon to a depth of at least 1 m. Higher solar exposure of the soil surface reduced initial contents of light sensitive acephate in top soils. The half-life for acephate in soil was 0.4-2.6 days. The study shows that soil drenching treatment with application of high rates and high volumes of acephate and chlorpyrifos onto freshly tilled soils in humid tropics causes extensive pesticide transport via solution and particulate matter to subsoils. It is recommended lower rates and volumes should be used to rectify the shortcoming of this practice.