Note

Field-Scale Runoff of Pesticides from Upland Fields under Natural Rainfall

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INTRODUCTION

The occurrence of water runoff from croplands has raised concern over contamination by pesticides of public water sources.¹⁾ Thus, experiments with artificial and natural rainfall have been performed to investigate field-scale runoff.^{2,3)} Furthermore, a small-scaled indoor runoff test system⁴⁾ with controlled rainfall conditions was also developed, due to the rarity of field-scale runoff events. However, tests have mainly been performed on fields of Ando soil, which covers more than 40% of upland fields in Japan. Other kinds of soils may respond differently to field-scale runoff.⁵⁾

In this study, runoff events in a field of Gray lowland soil, which covers around 5% of upland fields in Japan, were observed in the rainy season (from May to July) of 1997. The pesticides in surface flow water and residues in the soil surface layer were analyzed. Water runoff from the field of Gray lowland soil was compared with that in a field of Ando soil in the typhoon season (from September to October) of 1997. Furthermore, the indoor runoff test system with artificial rainfall was used to better understand the runoff on Gray lowland soil.

MATERIALS AND METHODS

1. Location and Conditions of Test Fields

The runoff tests were conducted in two test fields, A and B, located on the Miyazaki Experiment Station of the Japan

Plant Protection Association (JPPA) in Sadohara, Miyazaki Prefecture, Japan. Test field A is composed of Gray lowland soil. Field B was dressed with Ando soil to a thickness of approx. 30 cm on August 2, 1997. Soil properties are listed in Table 1.

Both fields had an area of 500 m² (20 m wide and 25 m long). Field A was sloped to an angle of 1.7° (A1) in the 1st experiment which was conducted from May to July, 1997. In field A1, cabbages (cv. Shutoku) were planted on 12 ridges oriented along the slope on May 12. In the 2nd experiment, field A1 was sloped to an angle of 1.15° (A2) on August 3. In field A2, Japanese radishes (cv. Taibyou-sobutori) were sown on 32 ridges oriented along the slope on October 1. Field B with the surface of Ando soil was also sloped to the same angle as field A2 on August 3 and seeds were sown on October 1. The experiment was conducted from September to November.

Precipitation data were obtained at 10 min intervals by an automatic weather recording system (KADEX-UP, KONA system Co., LTD.)

2. Pesticides

In the 1st experiment on field A1, three applications of pesticide (P1–P3) were employed. First, Diazinon granule was applied (P1) with broadcast treatment at a rate of a.i. 300 g/10 a on May 12, just before the planting of cabbages. Then, a mixture of Chlorothalonil (TPN: 400 mg/l) and Dimethoate (430 mg/l) was sprayed (P2) onto cabbages at a rate of 239 l/10 a on June 30. Finally, eight days after the 2nd application, a mixture of TPN (400 mg/l), Diazinon (400 mg/l) and Dimethoate (430 mg/l) was applied (P3) at a rate of 224 l/10 a on July 8.

In the 2nd experiment on fields A2 and B, a mixture of TPN, Diazinon and Dimethoate of the same concentration as above was sprayed onto Japanese radishes at a rate of 194 l/10 a for field A2 and 178 l/10 a for field B on November 12.

3. Sample Collection

In the 1st experiment, ten liters of surface water was collected using a stainless steel bucket from field A1 during runoff after pesticide applications. The bucketful of water was allowed to settle for 10 min. Then, the supernatant (approx. 2 l) was collected as a water sample. As a soil sample, ten soil cores (5 cm in diameter and 5 cm in depth) were collected at random from test field A1.

In the 2nd experiment on fields A2 and B, no runoff event was observed after the 4th pesticide application. Thus, no sample was collected.

4. Pesticide Analyses

Pesticide residues in water and soil samples were analyzed by GC-MS as described previously.³⁾ Water samples were

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Table 1 Soil properties of test fields A and B.

Test field ^{a)}	Depth of soil layer (cm)	Soil texture ^{b)}	pH (H ₂ O)	CEC (mEq/100 g)	PAC ^{c)}	Three-phase distribution (at pF 1.5)			Dry soil density (g/cm ³)	Relative water permeability
						Gaseous phase	Liquid phase	Solid phase		
A	0-22	SL	5.98	17.16	890	30.5	29.7	39.8	1.04	High
	22-38	L				10.3	38.6	51.1	1.31	Medium
	38-42	SL				6.5	41.7	51.8	1.31	Low
	42-62	CL								Low
B	0-23	L	5.69	28.45	2550	36.4	44.4	19.2	0.46	High
	23-32	L				18.0	56.8	25.2	0.59	High
	32-69	CL				7.1	64.0	28.9	0.68	Medium
	69-	S								High

^{a)} A: a field of Gray lowland soil, B: a field of Ando soil. ^{b)} CL: clay loam, L: loam, S: sand, SL: sandy loam.

^{c)} phosphate absorption coefficient.

separated to aqueous phase and suspended solids (SS) samples, then analyzed separately.³⁾ The detection limits were 0.0005 mg/l for aqueous phase samples, 0.7–0.1 mg/kg for SS and 0.01 mg/kg for soil samples. The recovery of each pesticide was 86–96% for aqueous phase samples at 0.1 mg/l and 72–88% for soil samples at 1.0 mg/kg.

5. Indoor Runoff Test

The indoor runoff test system⁴⁾ was employed for analyzing water runoff on Gray lowland soil. In the tests, 200 ml samples of runoff water were collected continuously from 0.7 m² of test plot covered with Gray Lowland soil after 12, and 20 mm/hr of rainfall and with Ando soil⁴⁾ after 30 mm/hr of rainfall. Collection times for the samples from each test plot were measured. The Gray lowland soil used has the texture of clay loam (Clay 24.5%, silt 26.7%, sand 48.7%); organic carbon 1.69%, pH 5.5/H₂O and 5.0/KCl, CEC 10.7 mEq/100 g, phosphate absorption coefficient 889, and maximum water holding capacity 62.0%. The Ando soil used has a texture of clay loam (Clay 17.4%, silt 29.9%, sand 52.7%); organic carbon 3.42%, pH 6.1/H₂O and 5.1/KCl, CEC 25.5 mEq/100 g, phosphate absorption coefficient 1120, and maximum water

holding capacity 81.8%.

RESULTS

1. Water Runoff from Fields of Gray Lowland Soil and Ando Soil

The runoff events on test fields A1, A2 and B in 1997 are shown in Fig. 1 and Table 2. Amounts of water were measured using 20 l buckets and 100 l and 500 l tanks. In some runoff events, however, the amounts could not be measured due to overflow from the tanks. In series of runoff events within 6 hours caused by chain rainfall,⁶⁾ the events were counted as one runoff. A total of 13 runoff events were observed on test field A1 (Fig. 1) and 4 on field A2 (Table 2). On the other hand, only two runoff events were observed on field B following rainfall simulating a typhoon (Table 2).

2. Comparison of Gray Lowland and Ando Soils by Indoor Runoff Tests

In the indoor runoff tests, collection times for 200 ml of runoff water from the test plots of Gray lowland soil and Ando soil are shown in Fig. 2. Runoff from Gray lowland soil at 12 mm/hr of rainfall occurred more easily than that

Fig. 1 Precipitation (mm) per day and runoff events (▲) from May 12 to July 15 1997. Arrows indicate the dates of the 1st to 3rd pesticide applications (P1–P3), and of soil sample (S2–S5) and water sample (W1–W7) collections, respectively.

Table 2 Occurrence of water runoff from test fields A2 and B in September and October 1997.

Occurrence of runoff events	Amount of precipitation (mm)	Maximum rainfall (mm/hr)	Water runoff			
			Field A2		Field B	
			Amount (ℓ)	Ratio (%)	Amount (ℓ)	Ratio (%)
Sep.8,3:10-5:30	13.5	11.5	430	6.4	- ^{b)}	
Sep.12,21:20-22:40	20.0	19.5	45	0.5	-	
Sep.16,1:00-13:00	233.0	33.0	OF ^{a)}	OF	410	0.4
Oct.2,8:10-10:20	21.0	11.5	1100	10.5	-	
Oct.2,11:30-14:20	48.0	23.0	12200	50.8	1590	6.6
Oct.2,14:20-16:20	17.5	13.0	OF	OF	740	8.5

^{a)} OF: Amount of runoff was not measured due to overflow from collection tanks. ^{b)} No runoff event was observed.

Fig. 2 Accumulated collection time for every 200 ml of runoff water from each test plot (0.7 m²) of Gray lowland soil (GLS) at 12 (■) and 20 mm/hr (●) of rainfall and Ando soil (AS) at 30 mm/hr (◇) of rainfall in the indoor runoff test.

from Ando soil at 30 mm/hr of rainfall. When the pF value in Ando soil was around 1.6 (saturated soil moisture), runoff was observed as in a previous report.⁴⁾ In Gray lowland soil, however, runoff was observed at a pF value of even 2.9. During the runoff tests, soil moisture (pF value) at a depth of 15 cm in the test plots of Gray lowland soil did not change, even though the surface of the test plots was tilled thoroughly before testing.

3. Pesticide Runoffs and Residue on Gray Lowland Soil

Seven water samples (W1 to W7) were collected from several runoff events on field A1 (Fig. 1). Sample W1 was collected from 419 l of runoff water. The amount of runoff water relative to precipitation was 9.9%. Samples W2 and W3 were collected from a single event, which induced 58 l of runoff water. The percentage of runoff water was 1.2%. Sample W4 was collected just after a runoff event started, W5 at the middle and W6 just before the end. In this event, the amount and extent of runoff was 1440 l and 36.0%. Furthermore, sample W7 was collected early (72.5 l) in a runoff event, which finally produced 3603 l of water runoff. The percent runoff was 39.0%. The pesticide concentrations in the water samples are shown in Table 3.

Five soil samples (S1 to S5) were also collected from field A1 just before and after the pesticide applications and after the runoff events (Fig. 1). Pesticide residues in soil are also

shown in Table 3. Although 345 mm of precipitation and 7 runoff events were observed from the 1st application to the collection S2 (55 days), approx. 1% of the Diazinon applied was still detected in the soil (S2). Although three water samples (W1, W2 and W3) were taken between S2 and S3, the concentrations of Diazinon in the samples were below the detection limit. No TPN was detected from the soil (S2) 6 days after the 2nd application though only 4.5 mm of rainfall and no runoff were observed during the 6 days. However, very little TPN was detected in the water samples W1 to W3 between 6 and 8 days after the 2nd application.

DISCUSSION

In previous studies,^{2,3)} little water runoff had been observed on fields of Ando soil in Ushiku, Ibaraki. However, water runoff on Gray lowland soil seemed to occur quite frequently. In the present study, the relative water permeability was high in the plowed layer of field A, but low at deeper layers. Thus, rainwater may have difficulty percolating downward through Gray lowland soil. On the other hand, in field B with Ando soil, the relative water permeability was high through deeper soil layers (Table 1). Based on the soil properties of the fields, field A (Gray lowland soil) seemed to more easily induce water runoff than field B (Ando soil). This was supported by the results of the indoor runoff tests (Fig. 2).

As the slope of field A2 was gentler than that of field A1, a higher intensity of rainfall would be required for runoff to occur. Moreover, more intensive rainfall would be required in field B than field A2. When the average intensity of rainfall was more than 5 mm/hr in field A1, over 10 mm/hr in field A2 and more than 20 mm/hr in field B, runoff was induced. Based on a previous study,⁴⁾ the occurrence of runoff on fields of Ando soil required not only intense (around over 20 mm/hr) rainfall but also more than 30–60 mm of precipitation before the occurrence. This is one reason why water runoff did not occur in field B at 19.5 mm/hr of rainfall on September 12 (Table 2).

In many studies^{7,8)} and our previous studies,^{2–4)} pesticide runoff reached a maximum when rainfall occurred immediately and intensely after pesticide application. In the present study, the concentration of runoff pesticides was also higher

Table 3 Days after pesticide applications and pesticide concentrations in the collected samples.

Days after pesticide application ^{a)}	Collected sample ^{b)}	Pesticide concentration (mg/l and mg/kg)					
		TPN		Diazinon		Dimethoate	
		Water (% on SS)	Soil	Water (% on SS)	Soil	Water (% on SS)	Soil
-1	S1		<0.01		<0.01		<0.01
0 (1 st application) (7 runoff events)							
49 0 (2 nd)							
55 6	S2		<0.01		0.02		0.16
56 7	W1	0.0031		<0.0005		0.0534	
57 8	W2	0.0008		<0.0005		0.0096	
	W3	0.0005		<0.0005		0.0093	
57 8	S3		<0.01		0.04		0.12
57 8 0 (3 rd)							
57 8 0	S4		0.20		0.26		0.43
57 8 0	W4	1.3320 (96%)		0.1222 (36%)		4.1562 (1%)	
	W5	0.2657 (78%)		0.0854 (33%)		1.9343 (1%)	
	W6	0.0767 (47%)		0.0490 (44%)		0.2581 (1%)	
57 8 0	S5		0.09		0.16		0.30
58 9 1	W7	0.0281 (37%)		0.0137 (2%)		0.1507 (1%)	

^{a)} 1st application: Diazinon granular, 2nd: mixture of TPN and Dimethoate, 3rd: mixture of TPN, Diazinon and Dimethoate. ^{b)} S1 to S5: soil samples, W1 to W7: water samples. Pesticide concentrations of runoff water include the residues on SS.

in W4 than W1. Among three pesticides, TPN mainly ran off with fine soil particles (SS), though the percentage of TPN in SS decreased from 96% (W4) to 47% (W6). TPN concentrations in the aqueous phase of W4, W5 and W6 without SS were only but constantly around 0.05 mg/l. On the other hand, the percentages of the other two pesticides in SS were 33–44% (Diazinon) and 1% (Dimethoate) (Table 3).

Pesticide concentrations in S5 indicate that approx. 55% of TPN, 38% of Diazinon and 30% of Dimethoate seemed to be lost from the soil surface layer (S4) in a single runoff event. As over 70–90% of pesticides in Ando soil were lost in the previous study,²⁾ the extent to which pesticide dissipates from the surface layer is smaller for Gray lowland soil than Ando soil. The result suggests that the pesticides on Gray lowland soil are mainly removed horizontally by rainfall, while those on Ando soil are removed not only horizontally but also vertically. In a previous study on Ando soil (Ushiku),²⁾ the order of pesticide dissipation from the surface layer after a runoff event was Dimethoate > TPN > Diazinon. The order corresponded with that of half-life in the field.⁹⁾ However, in this experiment on Gray lowland soil, it was TPN > Diazinon > Dimethoate. This characteristic of runoff would be induced by the properties of the soil and/or climatic conditions although more tests are required to make a conclusion.

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要 約

畑地圃場における自然降雨による農薬の地表流出

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宮崎県佐土原町の圃場において、キャベツを定植した灰色低地土の緩斜面圃場 (A1: 1.7°, 5 a) で1997年5~7月の梅雨期に地表水の流出が計13回観察された。この圃場にダイアジノン粒剤の定植時処理 (a.i. 300 g/10 a), その55日後に TPN (400 mg/l) とジメトエート (430 mg/l) の混用液 (239 l/10 a), その8日後に TPN, ダイアジノン (400 mg/l) とジメトエートの混用液 (224 l/10 a) を散布した。表流水によって流出した TPN の96% (流出直後) から47% (終了直前) は、浮遊物質 (SS) とともに

流出した。一方、ダイアジノンとジメトエートはそれぞれ33~44%および1%とほぼ一定の割合でSSとともに流出した。また、同年9~10月の台風時期にはA1圃場の傾斜を1.15°に調整した圃場 (A2) と黒ボク土の圃場 (B, 5 a, 傾斜1.15°) にダイコンを播種して地表水の流出頻度を比較した。その結果、灰色低地土では4回、黒ボク土では台風時の降雨によって2回の地表流出が認められた。灰色低地土のA1圃場では平均降雨強度5 mm/hr 前後以上で、A2圃場では10 mm/hr 以上の降雨によって、また黒ボク土のB圃場では20 mm/hr 以上の降雨によって地表水の流出が生じた。さらに、人工降雨装置を用いた屋内小規模地表流出試験系でも灰色低地土からは黒ボク土よりも容易に表流水が発生した。