농약과학회지 제8권 제4호(2004)
The Korean Journal of Pesticide Science
Vol. 8, No. 4. pp.299~308(2004)

Fate of the herbicide bensulfuron-methyl in a soil/rice plant microecosystem

Jae Koo Lee*, F. Führ[1], Jeong Wook Kwon, Ki Chang Ahn, Ju Hyoung Park, and Yong Pil Lee

Department of Agricultural Chemistry, Chungbuk National University, Cheongju 361-763, Korea and [1]Institut für Chemie und Dynamik der Geosphäre Institut 5:Radioagronomie, Forschungszentrum Jülich, D-52428, Germany

Abstract : In order to elucidate the behavior of bensulfuron-methyl, a sulfonylurea herbicide, in a soil/plant microecosystem, rice plants (*Oryza sativa* L.) were grown for 12 weeks in the specially made stainless steel pots (17 ㎝ I.D. × 10 ㎝ H.) containing two different paddy soils treated with fresh and 13-week-aged residues of [phenyl-^{14}C]bensulfuron-methyl, respectively. During the aging period, the mineralization to $^{14}CO_2$ from soil A (OM, 3.59%; CEC, 7.65 cmol$^+$ kg^{-1}; texture, sandy clay loam) and B (OM, 1.62%; CEC, 4.51 cmol$^+$ kg^{-1}; texture, sandy loam) amounted to 6.79 and 10.15% of the originally applied [^{14}C]bensulfuron-methyl, respectively. The amounts of $^{14}CO_2$ evolved from the soils with fresh residues were higher than those from the soils with aged residues. At harvest after 12-week growing, ^{14}C-radioactivity absorbed and translocated into rice plants from soils A and B containing fresh residues of bensulfuron-methyl was 1.53 and 4.40%, while 4.04 and 6.37% in the two soils containing aged residues, respectively. Irrespective of aging and soil type, the ^{14}C-radioactivity remaining in soil ranged from 80.41 to 98.87% of the originally applied [^{14}C]bensulfuron-methyl. The solvent extractability of the soils was 39.25~70.39%, showing the big differences among the treatments. Most of the nonextractable soil-bound residues of [^{14}C]bensulfuron-methyl were incorporated into the fulvic acid fraction(61.32~76.45%). Comparing the microbial activity of the soils with rice plants grown with that of the soils without them, the former was 1.6~3.0 times higher than the latter. However, it did not correlate with the $^{14}CO_2$ evolution.(Received November 10, 2004; accepted December 20, 2004)

Introduction

Bensulfuron-methyl, methyl α-(4,6-dimethoxy pyrimidin-2-ylcarbamoyl- sulfamoyl)-*o*-toluate, is one of the sulfonylurea herbicides which are known to inhibit branched chain amino acid biosynthesis by interference with the enzyme acetolactate synthase(ALS)(Smith, 1991). This herbicide has a broad-spectrum for the control of most broad-leaved grasses and sedges in transplanted or direct-seeded paddy rice(Yuyama et al., 1984). The adsorption, degradation, and leaching processes on soils have been described(Nicosia et al., 1991; Cavanna et al., 1998). Also, uptake and distribution of bensulfuron-methyl in rice were investigated by Yuyama et al (1987[a]). They used a half-strength complete nutrient solution(pH 5.8) for short-term uptake studies and a small pot (16 cm diameter) containing Sassafras sandy loam soil for long-term studies. However, the long-term covered only 7 days and the experiment was carried out in a growth chamber. In another investigation, Yuyama et al. (1987[b]) reported the relationship between soil and water on the behavior of bensulfuron-methyl in the simulated paddies, indicating that binding of bensulfuron-methyl to the soil was correlated with soil characteristics. The objective of our investigation is to elucidate the fate of the fresh and aged residues of bensulfuron-methyl in a

*Corresponding author(Fax : +82-43-271-5921, E-mail : jklee@cbnu.ac.kr)

Table 1. Physicochemical properties of the soils used

Soil	pH (H_2O)	OM (%)	C.E.C. ($cmol^+ kg^{-1}$ soil)	Particles (%)			Texture[a]
				Sand	Silt	Clay	
A	5.54	3.59	7.65	62.7	8.5	28.8	SCL
B	5.44	1.62	4.51	78.0	6.4	15.6	SL

[a]SCL, Sandy clay loam ; SL, Sandy loam.

microecosystem planted with rice.

Materials and Methods

Soils used

The physicochemical properties of the two soils are presented in Table 1.

Chemicals

Uniformly benzene-ring-labelled [^{14}C]bensulfuron-methyl (specific activity: 2.1275 MBq mg^{-1}) and cold bensulfuron-methyl(> 99.4% purity) were provided by E. I. Du Pont de Nemours & Co. (Wilmington, Del., USA).

Formation of soil-aged bensulfuron-methyl residues

On the basis of the degradation rate of [^{14}C]bensulfuron-methyl in soil which had been obtained from a preliminary study, two soils treated with a mixture of ^{14}C-labelled and nonlabelled bensulfuron-methyl were aged at 22±1℃ for 13 weeks. The initial soil treatment levels of [^{14}C]bensulfuron-methyl to prepare the aged residues for soils A and B were 795.61 KBq/6.5 kg soil and 750.14 KBq/6.5 kg soil, respectively. The total bensulfuron-methyl level(^{14}C-labelled and nonlabelled) was 0.05 mg kg^{-1} soil and the moisture content was 40% maximum water-holding capacity of the soils. CO_2-free air was supplied throughout the aging period.

Experimental design for growing rice plants

For growing rice plants on soils containing fresh and 13-week-aged residues of [^{14}C]bensulfuron-methyl, each treatment was done in triplicate. The control without growing rice plants was only one treatment. The ^{14}C-radioactivity of fresh residues treated to both soils A and B was 138.29 kBq/1.3 kg soil and those of aged residues treated to soils A and B were 148.01 and 134.70 kBq/1.3 kg soil, respectively.

Growing of rice plants

After the aging period of 13 weeks, the soils were air-dried and their radioactivities were measured by combustion with a biological oxidizer(R.J. Harvey Instrument Corp.). For growing rice plants, the soils were fertilized with N-P-K at the ratio 15:9:11 kg/10a, respectively. The two treated soil samples containing freshly applied bensulfuron-methyl and 13-week-aged residue were put into specially devised pots made of stainless steel (17 cm I.D.×10 cm H); 50-day-grown rice plant seedlings were transplanted into the soils. Eight seedlings were grown with two seedlings per hill. Rice plants were grown in a plastic film house with proper ventilation for 12 weeks. Moisture was supplied once per day at the early stage and twice at the middle and late stages.

Mineralization to $^{14}CO_2$ and volatilization of [^{14}C]bensulfuron-methyl and its metabolites

During the experimental period, $^{14}CO_2$ and volatile substances evolved from [^{14}C]bensulfuron-methyl and its metabolites in soil were trapped in 1 N NaOH and 0.1 N H_2SO_4, respectively. The radioactivities were measured weekly.

Harvest of rice plants

After the experimental period of 12 weeks, the shoots and roots of rice plants were harvested separately. The roots were rinsed thoroughly with tap water to remove soil. After the fresh weights of the shoots and roots were measured, the samples were freeze-dried for 4 days

(Chem Lab Instruments Ltd., Model SB 4) and then weighed again.

Measurement of radioactivity

After the plants were harvested, the soils were air-dried and ground homogeneously. The radioactivities of soils, roots, and shoots were measured as described in detail in the previous paper(Lee *et al.*, 1991).

Extraction of soil samples

Twenty grams of air-dried soils were shaken with 100 mL of methanol-acetone(1:1, v/v) for 5 hrs and then centrifuged at 15,540 g for 10 min. The extraction continued until no more radioactivity was extracted.

Distribution of radioactivity of soil extracts between aqueous and organic phases

Ten milliliters of methanol-acetone extracts of soil were concentrated in vacuo and the residue was redissolved in a small amount of methanol, transferred to capped test tubes, and concentrated in the stream of nitrogen. Five milliliters of distilled water were added to it and the pH of the solution was adjusted to 2.0 with 2N-HCl. Five milliliters of dichloromethane were added to it and the test tube was shaken vigorously. After shaking, the radioactivities of 3 mL dichloromethane layer and 3 mL aqueous layer were measured using toluene cocktail and Aquasol, respectively.

Analysis of nonextractable soil-bound ^{14}C

Five grams of the soil samples, which were exhaustively extracted with methanol-acetone mixture, were extracted again with 0.1 M $Na_4P_2O_7$ to the extent that the radioactivity of the extract reached the background level. To the combined extracts was added concentrated HCl until no more precipitate was formed. This mixture was centrifuged at 15,930 g for 10 min. The supernatant and precipitate correspond to fulvic acid and humic acid, respectively. The precipitate was dried at 50 ℃ in an oven. The ^{14}C radioactivity incorporated into fulvic acid was measured in Aquasol and those into humic acid and humin were measured after combustion with a biological oxidizer.

Determination of microbial activity in soil by DMSO(dimethyl sulfoxide) reduction

To the sterilized 15 mL screw-capped tubes were added 1.5 g of air-dried soils and 300 μL of distilled water. After sealed tightly, the tubes were preincubated at 30℃ for 12 hrs. After the preincubation, 100 μL of 21% DMSO was added to the tube and it was incubated at 25℃ for 5 hrs. The tubes were agitated on a vortex mixer for 0.5 min and the resulting DMS gas collected in the headspace was analyzed with a GC-FID (HP 5890 A series Ⅱ Gas Chromatograph, Hewlett Packard Co.) The instrumental conditions are presented in Table 2.

Degradation of bensulfuron-methyl in soil

To 20 g on the dry weight basis of soils A and B were added [^{14}C]bensulfuron-methyl(10.7 KBq) and nonlabelled bensulfuron-methyl to make a total concentration of about 0.05 ppm. Water was then supplied to the soils to make the moisture content to

Table 2. GC-FID conditions for the determination of microbial activities in [^{14}C]bensulfuron-methyl-treated soils after the experiment by dimethyl sulfoxide (DMSO) reduction to dimethyl sulfide (DMS)

Column	HP-FFAP (50 m L.× 0.2 ㎜ I.D.×0.33 ㎛ film thickness)
Temperature	Oven: 35℃ for 8 min, then ramped at 2.5℃/min to 220℃ and held for 2 min
	Injector : 220℃
	Detector : 250℃
Flow rate	Carrier (N_2) : 0.1 mL/min
	Make-up : 30 mL/min
	H_2 : 30 mL/min
	Air : 370 mL/min
Injection volume	300 μL

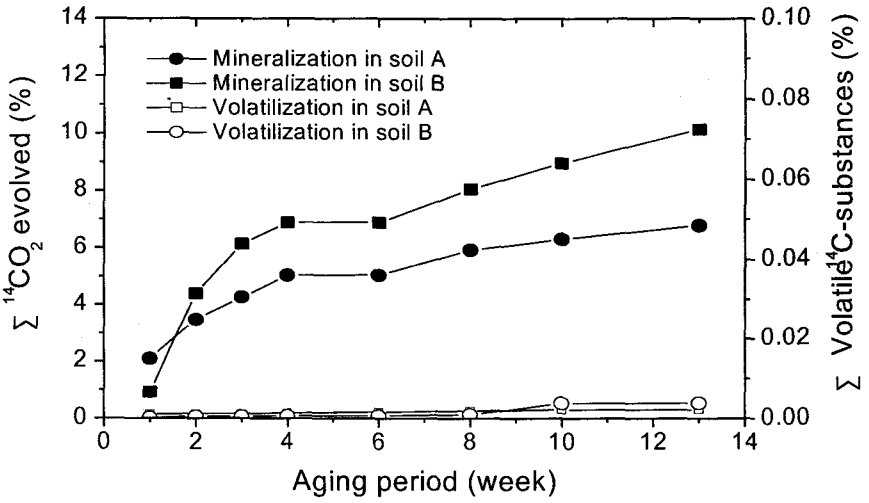


Fig. 1. Amounts of $^{14}CO_2$ and volatile ^{14}C-substances from soils during the aging period.

70% of the maximum water-holding capacity of each soil. The soils were incubated at 30℃ for 0, 30, 60, 90, and 120 days after treatment. The corresponding soils were extracted with methanol-acetone(1:1, v/v) for autoradiography.

Results and Discussion

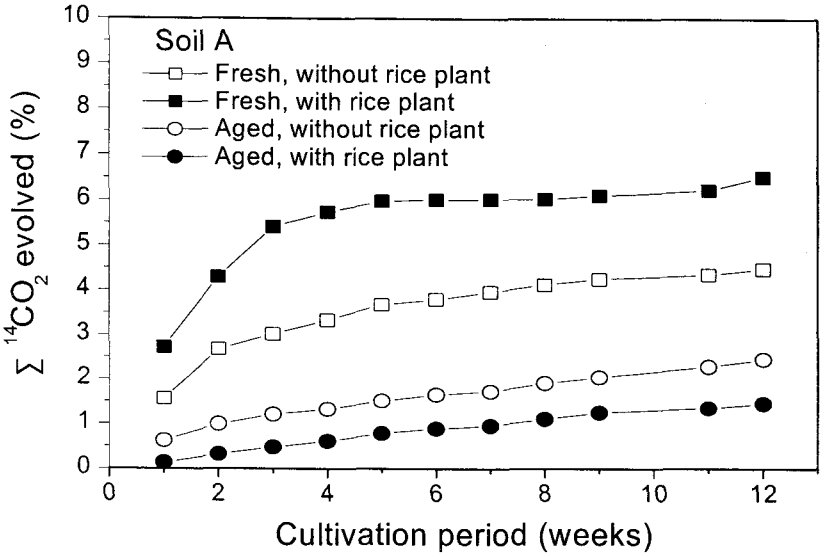
Formation of soil-aged residues

The amounts of $^{14}CO_2$ evolved during the aging period of 13 weeks were 6.79 and 10.15% of the originally applied [^{14}C]bensulfuron-methyl in soils A and B, respectively(Fig. 1). As seen Fig. 1, the evolution of $^{14}CO_2$ during the first 4 weeks in both soils increased very rapidly, and thereafter gradually. These results might be related to the adsorption of bensulfuron-methyl onto the soil constituents. Cavanna et al.(1998) reported that the adsoprtion of bensulfuron-methyl is a very fast process, reaching the equilibrium in 20~30 min, depending on soil texture and is mainly related with the clay mineral fraction. Similarly, in our investigation, the reason why more $^{14}CO_2$ (10.15%) was evolved from soil B than soil A would be due to the fact that the former contains less (organic matter, 1.62%; clay 15.6%; C.E.C., 4.51 $cmol^+ kg^{-1}$ soil) than the latter(organic matter, 3.59%; clay, 28.8%; C.E.C., 7.65 $cmol^+ kg^{-1}$ soil). That is, bensulfuron-methyl was bound more tightly to soil organic matter and/or clay in soil A than soil B. Therefore, the free bensulfuron-methyl residues would be susceptible to microbial and chemical attack in soil B. Meanwhile, the amount of volatile substances formed during the aging period was less than 0.01% of the originally applied ^{14}C in both soils.

Mineralization and volatilization during the cultivation period

Fig. 2 shows the amounts of $^{14}CO_2$ and volatile substances evolved from pot soils treated with [^{14}C]bensulfuron-methyl and planted with rice throughout the cultivation period of 12 weeks. Similarly to the results of the aging period, more $^{14}CO_2$ was evolved from soil B containing less amounts of organic matter and clay than soil A with more of them. It is quite conceivable that more $^{14}CO_2$ was evolved from the soils A and B containing fresh residues than from the soils with aged residues, because the aged residues are already so tightly bound to soil constituents that they are not vulnerable to microbial attack. An interesting finding as seen in Fig. 2 is that the fresh residues in soil A were mineralized more in the presence of rice plants than in their absence, whereas soil B showed the opposite result. This phenomenon will be due to the fact

(a)



(b)

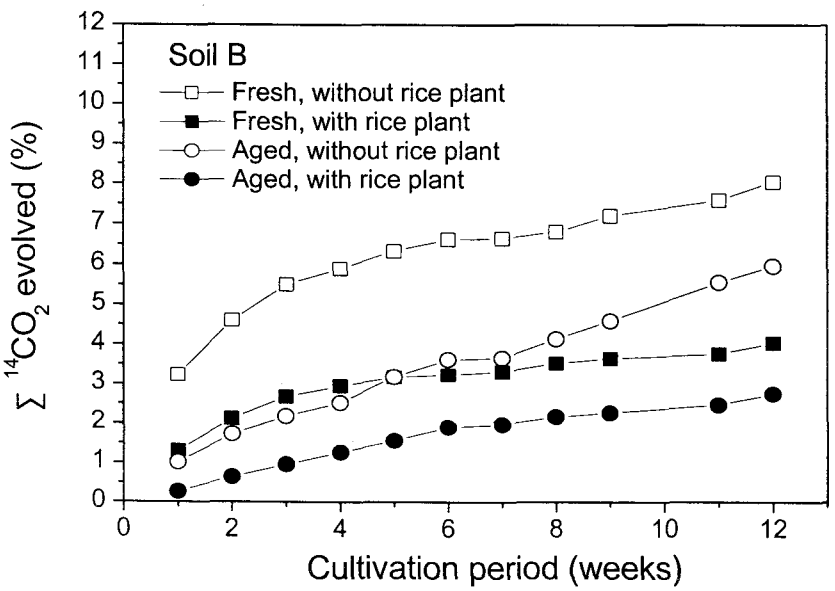


Fig. 2. Amounts of $^{14}CO_2$ evolved from soils A(a) and B(b) during the cultivation period. Volatile ^{14}C-substances were the background level.

that the acidic exudates from the rice roots helped to detach the bound residues from the soil matrices and the environment abundant in organic matter enhanced the microbial degradation, since bensulfuron-methyl is unstable under acidic conditions. However, in the case of soil B, the microbial activity was not much affected, because of the small amount of organic matter. The microbial activity in soil A with rice plants grown as seen in Fig. 3 supports this argument, as evidenced by the DMSO reduction. It is known that various kinds of sugars, amino acids, and organic acids are accumulated in the rhizosphere of rice plants(Kimura et al., 1977). In

Table 3. Bioavailability of the soil-treated [^{14}C]bensulfuron-methyl to rice plants during the cultivating period of 12 weeks

Soil	Type of residue	Uptake (%)		
		Root	Shoot	Total
A	Fresh	0.14±0.01 (0.07±0.01)[a)]	1.39±0.39 (0.17±0.03)	1.53
	13-week-aged	0.25±0.10 (0.14±0.02)	3.79±0.83 (0.42±0.08)	4.04
B	Fresh	0.22±0.13 (0.18±0.09)	4.18±2.09 (0.72±0.21)	4.40
	13-week-aged	0.19±0.02 (0.22±0.01)	6.18±1.04 (0.90±0.16)	6.37

[a)]Figures in parentheses represent concentrations of bensulfuron-methyl equivalent (μg/g) calculated on the basis of the specific ^{14}C-radioactivity (specific activity: 2.1275 MBq mg^{-1}) of the bensulfuron-methyl applied.

addition, a higher activity of dehydrogenase was reported in the corn rhizosphere than in root-free soil (Miskovic et al., 1977). In general, it is recognized that the rhizosphere is a zone of intense microbial activity because of its higher concentration of carbohydrates, amino acids, vitamins, and other growth-promoting substances(Nicholas et al., 1965).

Uptake of [^{14}C]bensulfuron-methyl residues by rice plants

The amounts of ^{14}C material absorbed and translocated by rice plants throughout the growing period of 12 weeks are presented in Table 3. It is noticeable that rice plants took up more ^{14}C material from the soils containing aged [^{14}C]bensulfuron-methyl residues than from the soils containing fresh ones. This result will be attributable to the fact that during the aging period, much of bensulfuron-methyl was degraded to smaller molecules, polar or nonpolar, which could be easily absorbed by rice plants. Concerning the translocation, bensulfuron-methyl taken up by the roots of rice plants is easily translocated to the shoots (Yuyama, 1987[a]). In soil A containing more organic matter, more clay, and higher cation exchange capacity, the amount of ^{14}C material translocated to the shoots was 9.9 times larger than that in the roots in fresh residues. Whereas, the ^{14}C material in the shoots is 15.2 times more than that in the roots in the aged residues. Meanwhile, in soil B containing less organic matter and clay, the amount of ^{14}C in the shoots was 19 times larger than that in the roots in the fresh residues. Whereas, the ^{14}C material in the shoots is 32.5 times more than that in the roots in the aged residues. These results indicate that bensulfuron-methyl is translocated very rapidly to the shoots and this rate depends on soil texture and the characteristics of the residues. As a whole, the results obtained are in accordance with those by Yuyama et al. (1987[b]), which were obtained from an only 7-day experiment. They showed that at a higher rate of application, the ^{14}C material translocated to the shoots was far more than that in the roots, compared with a lower rate of application.

Extraction of the residues and distribution of the ^{14}C material in the extracts between aqueous and organic phases

For the exhaustive extraction of [^{14}C]bensulfuron-methyl residues in soil, methanol-acetone(1:1, v/v) was used. When bensulfuron-methyl was aged in soil without rice plant for 13 weeks, 58 % of the originally treated ^{14}C-radioactivity was extracted from both soils A and B, irrespective of the physicochemical characteristics of the soils. However, when rice plants were grown on the soils containing fresh or aged residues, the extractive decreased drastically. This result will be due to the losses by rice plants, such as uptake and transpiration.

Table 4. Partitioning of the solvent extracts from [^{14}C]bensulfuron-methyl- treated soil samples in the absence and presence of rice plants between aqueous phase and organic phase. Aqueous phase+organic phase=100%

Soil	Type of residue	Rice planting	Solvent extractable[a)]	%Reduction in extractive[b)]	Distribution (%) of ^{14}C after partitioning	
					Aqueous phase	Organic phase
A	Aged	Before cultivation	57.81		9.37	90.63
B	Aged	"	57.61		8.38	91.62
A	Fresh	No	70.39		6.72	93.28
		Yes	65.25	7.30	5.60	94.40
	Aged	No	60.25		12.17	87.83
		Yes	55.33	8.17	10.59	89.41
B	fresh	No	61.52		7.35	92.65
		Yes	42.17	31.45	17.79	82.21
	Aged	No	59.93		11.58	88.42
		Yes	39.25	34.51	14.92	85.08

[a)]Extractant is a mixture of methanol:acetone(1:1, v/v).
[b)]Amount extracted without rice-Amount extracted with rice/Amount extracted without rice × 100.

This phenomenon was especially conspicuous in soil B with less organic matter, less clay content, and lower C.E.C.(Table 4). Meanwhile, as seen in Table 4, partition results of the extractives indicated that more than 82 % of the extracts was nonpolar.

Distribution of soil-bound residues

Table 5 presents the distribution of the nonextractable bound residues formed from soils containing different [^{14}C]bensulfuron-methyl residues. The amounts of ^{14}C material incorporated into humic substances in soil are in the decreasing order of fulvic acid>humin>humic acid. More than 61.33% of the nonextractable bound residues of [^{14}C]bensulfuron-methyl were incorporated into fulvic acid portion. The reason why more nonextractable bound residues were formed in soil where rice plants were grown is that the exudates from the roots helped to bind the bensulfuron-methyl residues to soil matrices. Moreover, the fact that more nonextractable bound residues were formed in soil B containing less organic matter, less clay, and lower cation exchange capacity than soil A implies that the root exudates of rice plants played an important role in forming bound residues.

Table 5. Change in the nonextractable soil-bound residues of [^{14}C]bensulfuron-methyl in the absence and presence of rice plants. Fulvic acid+humic acid+humin=100%

Soil	Type of residue	Rice planting	Non-extractable	Fulvic acid	Humic acid	Humin
			%			
A	Aged	Before cultivation	42.19	70.66	13.28	16.06
B	Aged	"	42.39	74.22	11.62	14.16
A	Fresh	No	29.61	68.07	14.57	17.36
		Yes	34.75	65.03	16.19	18.78
	Aged	No	39.75	76.45	10.63	12.92
		Yes	44.67	66.31	18.75	14.94
B	Fresh	No	38.48	67.02	12.76	20.22
		Yes	57.83	69.41	11.06	19.53
	Aged	No	40.07	61.33	11.70	26.97
		Yes	60.75	68.79	11.93	19.28

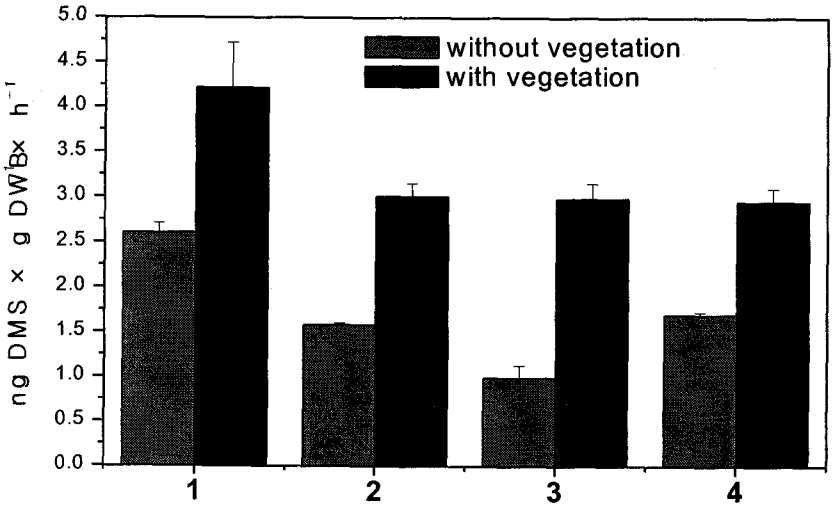


Fig. 3. Determination of microbial activities in the [^{14}C]bensulfuron-methyl- treated soils with and without vegetation of rice plants by the reduction method of dimethyl sulfoxide (DMSO) to dimethyl sulfide. 1, Soil A with fresh residues ; 2, Soil A with aged residues ; 3, Soil B with fresh residues ; 4, Soil B with aged residues

Changes in microbial activities in soil after growing rice plants

The changes in microbial activities in soils A and B, where [^{14}C]bensulfuron-methyl was treated and rice plants were grown, were determined by the DMSO reduction method. As seen in Fig. 3, the microbial activities increased 1.6~3.0-fold after growing rice plants, regardless of the physicochemical characteristics of the soils. This result will be due to the exudates which contain various organic substances and hence stimulate microbial activities(Curl and Truelove, 1986). However, there was no positive correlation between mineralization to $^{14}CO_2$ and microbial activities during the growing period of rice plants.

Degradation of bensulfuron-methyl in soil

Fig. 4 shows the autoradiogram of the extracts of soils A and B which were incubated for certain periods of time. A common degradation product turned out to be bensulfuron which is the demethylation product of bensulfuron-methyl. In addition, two other polar products were obtained from both soils, one of them (metabolite I) being detected only in soil B. Earlier, however, Takeda et al. (1986) reported the 4-hydroxy analog of DPX-F5384 (bensulfuron-methyl) as a metabolite in rice leaves.

Balance sheet of [^{14}C]bensulfuron-methyl in a microecosystem

Table 6 summarizes the fate of [^{14}C]bensulfuron-methyl residues, fresh and 13-week-aged, treated to the soils in a soil/rice plant microecosystem. It is noteworthy that the aged residues were more available to rice plants than the fresh ones in the presence of rice plants. This result indicates that the aging of bensulfuron-methyl brought about some degradation into more bioavailable compounds in soil. Bensulfuron-methyl persists in soil as the intact form and partially some degradation products, as evidenced by Fig. 4. The reason why the recoveries are relatively lower in the soils with rice plants grown will be due to some losses through transpiration by rice plants. In addition, the smaller amounts of ^{14}C remaining in soil B compared with soil A will be due to the easy uptake by rice plants (Table 3), as seen in soil characteristics.

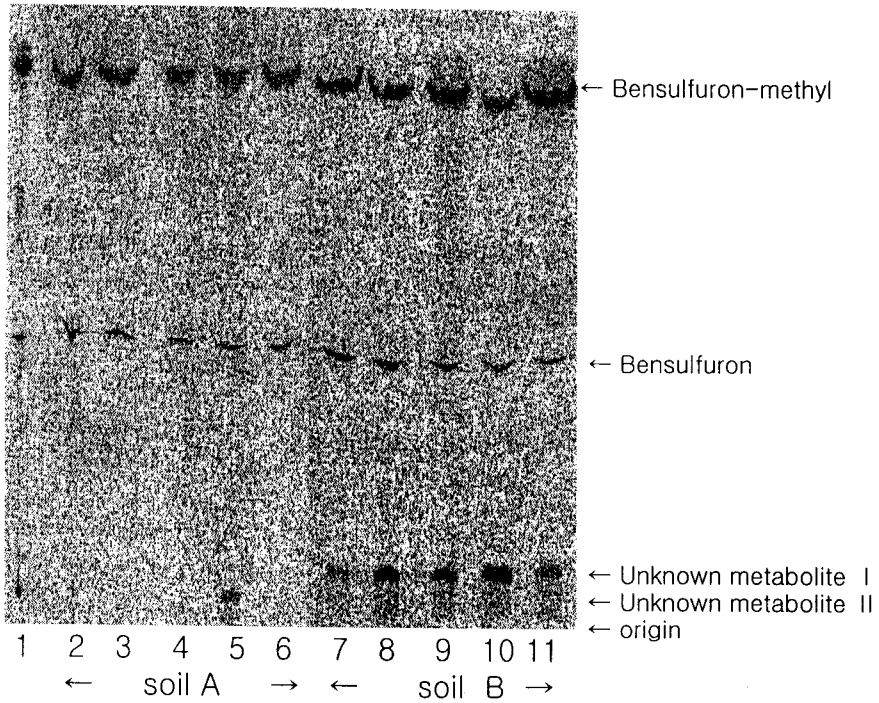


Fig. 4. Autoradiogram of the extracts of [^{14}C]bensulfuron- methyl-treated soils incubated for 0, 30, 60, 90, and 120 days at 30℃ after treatment. Developing solvent: methylene chloride-methanol-acetic acid=9:1:0.1, v/v/v.
1, Authentic[^{14}C]bensulfuron-methyl; 2 and 7, 0-day-aged; 3 and 8, 30-day-aged; 4 and 9, 60-day-aged; 5 and 10, 90-day-aged; 6 and 11, 120-day-aged.

Table 6. Balance sheet of the fresh and aged [^{14}C]bensulfuron-methyl residues in a soil/rice plant microecosystem

Soil	Type of residue	Rice planting	$^{14}CO_2$ evolved	^{14}C in rice plant	^{14}C remaining in soil	Recovery
			---------- % ----------			
A	Fresh	No	4.48	-	96.11	100.59
		Yes	6.51	1.53	87.34	95.38
	Aged	No	2.46	-	98.87	101.33
		Yes	1.46	4.04	90.43	95.93
B	Fresh	No	8.03	-	90.65	98.68
		Yes	4.03	4.40	80.41	88.84
	Aged	No	5.97	-	94.80	100.77
		Yes	2.75	6.37	83.74	92.86

Acknowledgment

This work was supported by Chungbuk National University Grant in 2004.

Literature cited

Alef, K. and D. Kleiner (1989) Rapid and sensitive determination of microbial activity in soils and in soil aggregates by dimethyl sulfoxide reduction. Biol. Fertil. Soils 8:349~355.

Cavanna, S., E. Garatti, E. Rastelli, G. P. Molinari(1998) Adsorption and desorption of bensulfuron-methyl on Italian paddy field soils. Chemosphere 37:1547~1555.

Curl, E. A. and B. Truelove (1986) Root Exudates, pp.55~92, In the Rhizosphere Springer-Verlag, Berlin.

Kimura, M., H. Wade, and Y. Takai (1977) Studies on the rhizosphere of paddy rice (part 4) : Physical and

chemical features of rhizosphere (Ⅱ). Jpn. J. Soil Sci. Plant Nutr. 48:540~545.

Lee, Jae Koo, Kee-Sung Kyung, and W. B. Wheeler (1991) Rice plant uptake of fresh and aged residues of carbofuran from soil. J. Agric. Food Chem. 39: 588~593.

Miskovic, K., B. Rasovic, L. Starcevic, and N. Milosevic (1977) Effect of nitrogen on dehydrogenase activity and the number of actinomycetes and fungi in soil and rhizosphere of corn. Mikrobiologiya 14:105~116.

Nicholas, D. J. D. (1965) Influence of the rhizosphere on the mineral nitrogen of the plant. In Ecology of soil-borne plant pathogens; Baker, K. F., Snyder, W. C., Eds.; University of California Press : Berkeley, pp.210~217.

Nicosia, S., C. Collison, and P. Lee (1991) Bensulfuron-methyl dissipation in California rice fields and residue levels in agricultural drains and the Sacramento River. Bull. Environ. Contam. Toxicol. 47:131~137.

Smith, C. (1991) Sulfonylurea Herbicides, PJB Publications Ltd. 9~10.

Takeda, S. , D. L. Erbes, P. B. Sweetser, J. V. Hay, and T. Yuyama (1986) Mode of herbicidal and selective action of DPX-F5384 between rice and weeds. Weed Res. Japan. 31:157~163.

Yuyama, T., S. Takeda, H. Watanabe, T. Asami, S. Peudpaichit, J. L. Malassa, and P. Heiss.(1984) DPX-F5384 a new broad-spectrum rice herbicide. Proc 7th Indonesian Weed Science Society Conf., Vol. 1, pp.89~94.

Yuyama, T., R. C. Ackerson, and S. Takeda(1987[a]) Uptake and distribution of bensulfuron methyl (DPX-F 5384) in rice. Weed Res. Japan. 32:173~179.

Yuyama, T., R. C. Ackerson, S. Takeda, and Y. Watanabe (1987[b]) Soil and water relationship on the behavior of bensulfuron-methyl (DPX-F 5384) under the paddy field conditions, Weed Res. Japan. 32:282~291.

벼 재배 microecosystem 내에서 제초제 bensulfuron-methyl의 행적

이재구*, F. Führ[1], 권정욱, 안기창, 박주형, 이용필(충북대학교 농화학과, [1]독일 원자력연구소 방사선농학연구소)

요약 : 토양/벼 microecosystem내에서 sulfonylurea계 제초제 bensulfuron- methyl의 행적을 구명하기 위하여 [Phenyl-^{14}C]bensulfuron-methyl의 신생(fresh) 잔류물과 13주간 숙성된 숙성(aged) 잔류물을 처리한 2종의 상이한 논토양을 stainless steel pot (내경, 17 cm × 높이 10 cm)에 담고 벼 (*Oryza sativa* L.)를 12주간 재배 하였다. 토양 A(유기물 함량, 3.59%; 양이온 치환용량, 7.65 cmol$^+$ kg^{-1}; 토성, 사질 식양토)와 토양 B(유기물 함량, 1.62%; 양이온 치환용량, 4.51 cmol$^+$ kg^{-1}; 토성, 사양토)에서 [^{14}C]bensulfuron-methyl이 13주간의 숙성 기간 동안 $^{14}CO_2$로 무기화된 량은 최초 처리량의 각각 6.79와 10.15% 이었다. 신생 잔류물을 함유한 토양으로부터 방출된 $^{14}CO_2$량은 숙성 잔류물을 처리한 토양으로부터 방출된 량보다 많았다. 12주간 벼를 재배하고 수확하였을 때 신생 잔류물을 함유한 토양 A와 B로부터 벼가 흡수 이행한 ^{14}C량은 각각 최초 처리량의 1.53과 4.40%이었고 숙성 잔류물을 함유한 토양 A와 B로부터 흡수 이행한 양은 최초 처리량의 4.04와 6.37% 이었다. 숙성과 토성에 관계없이 토양에 잔류하고 있는 ^{14}C량은 최초처리량의 80.41~98.87% 이었다. 유기용매로는 토양에 잔류하는 ^{14}C 방사능의 39.25~70.39%를 추출할 수 있었고 bensulfuron-methyl의 추출불가 토양 흡착 잔류물의 대부분은 fulvic acid 부분에 혼입되어 있었다 (61.32~76.45%). 벼 재배 유무에 따른 미생물 활성을 비교한 결과 벼 재배시 두 토양에서 모두 미생물 활성이 벼를 재배하지 않은 경우의 1.6~3.0 배 이었으나 $^{14}CO_2$ 발생량과는 반드시 일치하지 않았다.

Key words : [^{14}C]bensulfuron-methyl, soil/rice plant microecosystem, fresh residue, aged residue, rice plant.

*연락저자(Fax : +82-43-271-5921, E-mail : jklee@cbnu.ac.kr)