

## Bentazon Leaching in Four Illinois Soils

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Bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide), a postemergence herbicide, was applied at 3.36 kg/ha to four soils in lysimeters where soybeans were growing in 1972 and 1973. Early-season, mid-season, and no supplemental irrigation treatments were applied. Lea-

chates were analyzed for bentazon. Bentazon leached through the soil in the initial leachate. No bentazon was detected in the leachates 60 days after application, regardless of when the irrigation was applied. Less than 2% of the applied bentazon was leached through the soils.

Bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide) is a relatively new herbicide which controls many troublesome broadleaf weeds in soybeans [*Glycine max* (L.) Merr.], but it is ineffective on grasses (Andersen et al., 1974; Wax et al., 1974). Applied to the foliage, this herbicide is very effective, but it has very little herbicidal activity when applied to the soil.

Although applied postemergence, much of the bentazon eventually reaches the soil for deposition. Bentazon was not adsorbed on any of 12 Illinois soils, but moved with the solvent front on soil thin-layer plates and soil columns (Abernathy and Wax, 1973). Bentazon appears to have anionic characteristics in aqueous systems (Abernathy and Wax, 1973). These results suggested that bentazon would readily leach through these soils. Our objective in this research was to ascertain the leachability of bentazon through four soils in lysimeters.

### MATERIALS AND METHODS

**Lysimeters.** The lysimeters were 0.91 m in diameter and 1.02 m deep. These lysimeters have been described (Stauffer and Smith, 1937) and the soils were fully described by Wascher et al. (1950). The soils have been in place in the lysimeters for more than 20 years. Briefly, the Saybrook and Elliott are moderately weathered soils derived from outwash and till, whereas Herrick and Cowden soils are derived from loess; Herrick is moderately weathered, and Cowden is strongly weathered. Organic matter content is 3.2, 4.1, 3.1, and 2.3 for the Saybrook, Elliott, Herrick, and Cowden soils, respectively. The lysimeters were maintained so that only leaching could occur; there was no surface runoff. Three treatments (described below) were put on each of the four soils in separate lysimeters.

**Herbicide.** An 80% wettable powder formulation of bentazon (designated BAS 3512H by BASF Corp.) was applied to the soils in the lysimeters. For the analytical determinations, technical bentazon was used as a standard.

**Treatments.** Beeson soybeans were planted on May 22, 1972 and June 11, 1973. When the soybeans attained the second trifoliolate leaf stage (June 6, 1972 and June 29, 1973), bentazon was applied to the soil surface at the rate of 3.36 kg/ha, nearly four times that recommended. Immediately after application, 0.6 cm of water was applied. Three irrigation treatments were begun, with one treatment on each of the three soil replicates: (a) early season ir-

rigation, in which 58.4 cm of water was applied from June 16 to Aug 11, 1972, and 26.7 cm from July 2 to July 27, 1973; (b) late season irrigation, in which 45.7 cm of water was applied from Aug 14 to Sept 25, 1972, and 21.6 cm from Aug 2 to Aug 22, 1973; and (c) no irrigation. The irrigated lysimeters received 2.5 cm of water at 2 to 3 day intervals. Irrigation water was added in 0.6-cm increments every half hour until the 2.5 cm was applied. All lysimeters received natural rainfall, besides irrigation.

**Soybean Harvest.** At maturity, Oct 3, 1972 and 1973, we excised the soybeans at the soil level, dried them at 65°, and then determined plant and seed weight. All the leaves had senesced at maturity, and were not harvested.

**Leachate Analyses.** The leachate from each lysimeter was collected in 12-l. ceramic jars. When at least 6 l. of leachate accumulated in the jars, the total volume was ascertained, a sample was taken for bentazon analysis, and the remainder was discarded.

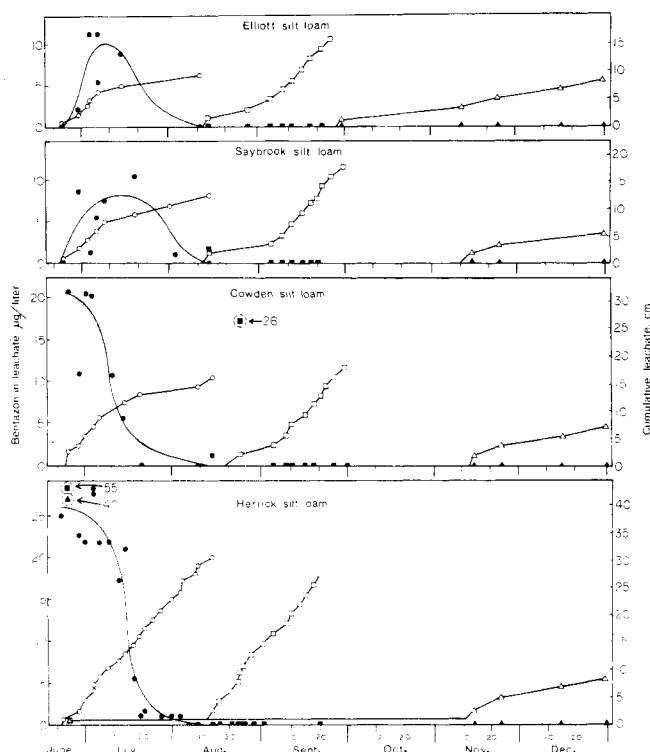
In 1972, a 500-ml sample of leachate was filtered through glass wool, and then lowered to pH 1 with HCl. The bentazon was extracted from the leachate by washing once with 70 ml of CH<sub>2</sub>Cl<sub>2</sub>, and then twice with 30 ml of CH<sub>2</sub>Cl<sub>2</sub>. After filtering through glass wool, the CH<sub>2</sub>Cl<sub>2</sub> was reduced to dryness in a rotary evaporator. The residue was transferred to a small vial with several washings of benzene. The benzene was evaporated under N<sub>2</sub>.

In 1973, we analyzed 1500-ml samples of the leachate for bentazon and AIBA (2-amino-*N*-isopropylbenzamide), a possible metabolite of bentazon. For the analyses, the leachate was first adjusted to pH 5.5, and then extracted three times with 50-ml portions of CH<sub>2</sub>Cl<sub>2</sub>, to extract AIBA. Next, the leachate was adjusted to pH 2.5 with HCl and extracted three times with 50 ml of CH<sub>2</sub>Cl<sub>2</sub>, to remove the bentazon. Both extracts were reduced to dryness as described for the 1972 samples.

**Thin Layer Chromatography.** Bentazon and AIBA were analyzed quantitatively and qualitatively by TLC. After the addition of benzene to the dried extracts (usually 50 µl), samples were spotted on silica gel coated, poly(ethylene terephthalate) sheets (Eastman type K301RZ) containing fluorescent indicator. Standards of 0.1 to 10.0 µg of bentazon or AIBA were also run. The sheets were developed in CHCl<sub>3</sub>-CH<sub>3</sub>OH (7:3) for the 1972 samples and in CHCl<sub>3</sub>-CH<sub>3</sub>OH-NH<sub>4</sub>OH (69:30:1) for the 1973 samples. Samples shown to contain bentazon were analyzed again as described. The spot size and intensity of the unknowns were compared to that of the standards, as viewed under ultraviolet (uv) light, to estimate the quantity present. If estimates of bentazon quantity varied greatly, samples were rerun until replicates agreed. To further confirm the identity of bentazon in the samples, we randomly selected about 25% of the samples shown to contain bentazon and chromatographed them on the sheets in ethyl acetate-acetic acid-H<sub>2</sub>O (8:1:1). In every sample, the suspected bentazon of the samples chromatographed identically with the technical bentazon. Identical retention times on GLC col-

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**Figure 1.** Bentazon concentration and accumulated leachate for the soils from the three irrigation treatments in 1972. Open symbols are leachate volumes; solid symbols are bentazon concentration in leachate. Circles represent the early irrigation; squares represent the late irrigation; triangles represent no irrigation. Although more leachate accumulated after irrigation ceased, the leachate volume data after irrigation terminated are not shown.

umns by use of an electrolytic detector further helped us confirm the identity of bentazon in these samples.

We detected 1.0 µg of bentazon or AIBA in untreated leachates with this procedure, when known quantities of these compounds were added. Recovery averaged nearly 100% for these tests.

## RESULTS AND DISCUSSION

Plant weight at maturity is given in Table I. The quantity of bentazon leached per month for the different treatments is shown in Table II. Leachate volume and bentazon concentration for the treatment in 1972 are presented in Figure 1. Table III lists the precipitation data.

Plants grew better in 1972 than in 1973, partly due to the longer growing season in 1972 (Table I). Bentazon treatments did not result in any visible soybean injury. Large differences in growth can be attributed to the irrigation treatments.

As expected, the bentazon that leached through the soils moved with the initial leachate (Table II and Figure 1). As a result, bentazon leached in response to rain or irrigation; mainly early irrigation caused the bentazon to leach in 1972, but the unusually high quantity of June and July precipitation caused the early leaching in the nonirrigated treatments in 1973. No bentazon was detected in leachates collected after Aug 17 of either year. In 1973, no leachate accumulated until July after bentazon application; leachates were not analyzed after Aug 31, because the bentazon leaching data resembled the 1972 data. Although the data are not shown, leachates were analyzed from all the 1972 treatments until Feb 1, 1973. Under natural rainfall in 1972, bentazon leached in June only in the Herrick soil (Figure 1); in other treatments irrigation resulted in bentazon leaching. Because bentazon moved with the initial leachate, very little additional bentazon leached after the ini-

**Table I.** Soybean Growth at Harvest for the Various Treatments

Year	Irrigation treatment	Dry wt, g/plant	
		Total plant	Seed
1972	June to Aug	40.2	21.9
	Aug to Oct	30.1	18.6
	None	26.3	16.1
1973	July	17.6	7.7
	Aug	24.1	12.6
	None	20.9	9.8
	LSD (0.05)	5.5	2.1

**Table II.** Monthly Bentazon Leaching for the Various Treatments in the Different Soils in 1972 and 1973 Where 3.36 kg/ha Was Applied

Soil	Irrigation treatment	g/ha for month			
		June	July	Aug	Sept
1972					
Elliott	June to Aug	0.30	3.35	0.00 <sup>a</sup>	0.00
	Aug to Oct	...	...	0.00	0.00
	None	...	...	...	0.00
Saybrook	June to Aug	1.37	3.95	...	...
	Aug to Oct	...	...	0.30	0.00
	None	...	...	...	...
Cowden	June to Aug	7.46	9.29	0.15	0.00
	Aug to Oct	4.87	0.00	0.00	0.00
	None	...	...	...	...
Herrick	June to Aug	10.50	21.00	0.00	0.00
	Aug to Oct	3.95	...	0.00	0.00
	None	9.74	...	...	...
1973 <sup>c</sup>					
Elliott	July		4.11	0.15	
	Aug		6.09	0.00	
	None		6.24	...	
Saybrook	July		6.24	0.00	
	Aug		6.09	0.76	
	None		1.22	...	
Cowden	July		17.97	0.00	
	Aug		7.77	0.15	
	None		12.49	...	
Herrick	July		65.47	0.00	
	Aug		6.09	0.00	
	None		15.84	...	

<sup>a</sup> 0.00 = no bentazon detected in the leachate. <sup>b</sup> ... = no leaching occurred during that month. <sup>c</sup> No leachate was collected in June or Sept of 1973.

tial early surge, even though the leachate continued to accumulate in the irrigated treatments.

Data in Figure 1 show the elution characteristics for bentazon in these soils. The 1973 data confirmed these 1972 data. Bentazon concentration increased initially, attained a maximum level, then decreased in the Elliott and Saybrook soils; in the Cowden and Herrick soils, the concentration was at a maximum early and then decreased rapidly. This indicates that the effective adsorption characteristics of bentazon are different in the till soils than in the loess soils. The concentration data (Figure 1) show that bentazon moved with the initial water in the lysimeters, as it did on soil-TLC plates and small columns in the laboratory (Aberrathy and Wax, 1973).

The maximum total bentazon recovered was less than 2% of that applied to these soils (Table II). Commonly, less

**Table III. Monthly Rainfall (cm)**

Year	Month						
	June	July	Aug	Sept	Oct	Nov	Dec
1972	8.7	6.6	14.5	22.0	5.4	10.6	12.5
1973	17.9	23.4	7.7	7.6	7.4	6.3	12.2

than 1% was recovered. In contrast, from 74 to 97% of the applied bentazon leached through soil columns in the laboratory (Abernathy and Wax, 1973). Most of the bentazon evidently was adsorbed in the lysimeters in the field, because it is not metabolized rapidly enough to disappear in 30 days. Bentazon half-life ranges from 10 to 30 days (Drescher, 1972). The differences in the quantity adsorbed between the field and laboratory studies could result from the bentazon not reaching adsorption equilibrium in the laboratory studies like it did in the field. Leachate was collected within hours after application on the laboratory columns, but not for days after application in the field. Bentazon may be completely adsorbed at equilibrium, but this may not occur for 30 or more days, as evidenced by the absence of bentazon in leachates from the lysimeters after the initial surge terminated. In addition, no bentazon leached in lysimeters where no leachate appeared for 60 days.

If bentazon ionizes in aqueous solution as proposed (Abernathy and Wax, 1973), then only less than 1 mequiv of anion exchange capacity per 100 kg of soil in the upper 15 cm of soil would be required to satisfy the exchange capacity of the 3.36 kg/ha of bentazon applied. Even these soils should have this amount of anion exchange. Bentazon ap-

pears not to be completely adsorbed by this means, because it was easily transported through the soils.

No AIBA was detected in any of the leachates analyzed in 1973.

Our results indicate that some of the soil-applied bentazon can leach through some Illinois soils, provided it rains enough to cause water movement through the soil within 60 days after application. Even though we applied four times the recommended rate to the soil (normal applications are applied to foliage), less than 2% of the applied bentazon was ever recovered in the leachate. Although some bentazon can leach through soils, its presence in aquatic systems is probably not a threat to aquatic food chains, because aquatic organisms do not accumulate the chemical to any significant degree nor is this herbicide greatly toxic to these organisms (Booth and Hansen, 1973).

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## Effect of Associated Anions on Ammonium Adsorption by and Desorption from Soils

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The effect of associated anions,  $\text{H}_2\text{PO}_4^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$ , on  $\text{NH}_4^+$  adsorption by 14 Trinidad soils showed that the  $\text{NH}_4^+$  adsorption maxima obtained from  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{NH}_4\text{NO}_3$  were 63 and 45%, respectively, of that from  $\text{NH}_4\text{H}_2\text{PO}_4$ . Conversely,  $\text{NH}_4^+$  desorption from soils was less when it was adsorbed from  $\text{NH}_4\text{H}_2\text{PO}_4$  than from either  $(\text{NH}_4)_2\text{SO}_4$  or  $\text{NH}_4\text{NO}_3$ . These effects were ascribed to the specific adsorption of  $\text{H}_2\text{PO}_4^-$  and  $\text{SO}_4^{2-}$  by soils.  $\text{NH}_4^+$  adsorption maxima were

correlated positively with CEC and negatively with total nitrogen content irrespective of associated anions. In addition, it was also correlated with oxalate extractable iron, base saturation, and dithionite extractable iron when the associated anions were  $\text{H}_2\text{PO}_4^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{NO}_3^-$ , respectively. The application of these observations to  $(\text{NH}_4)_2\text{SO}_4$ ,  $\text{NH}_4\text{H}_2\text{PO}_4$ , and  $\text{NH}_4\text{NO}_3$  fertilization of soils in the humid tropics was indicated.

The nature of the anion associated with ammonium ion has been found to influence the capacity for ammonium fixation. This was generally ascribed to be due to the effect of the anion on the pH of the soil. The effect of the anion on the adsorption capacity of the associated cation should also be considered. Thus, Leggett (1958) showed that in a number of different ammonium salts tested, the highest

sorption by soils and minerals was obtained with  $(\text{NH}_4)_2\text{HPO}_4$ . Stojanovic and Broadbent (1960) found that a small but consistently greater proportion of the ammonium ions added to soils as  $(\text{NH}_4)_2\text{HPO}_4$  or  $\text{NH}_4\text{NO}_3$  could be recovered by acidified salt solutions than when the ammonium ions were added as  $\text{NH}_4\text{OH}$  or  $\text{NH}_4\text{Cl}$ . However, Harada and Kutsuna (1954) observed that the ammonium fixation was the same, independent of whether ammonium was added as sulfate or chloride. In Hawaiian soils, Kanehiro et al. (1960) found that the sorption of ammonium ions was higher when applied as  $\text{NH}_4\text{H}_2\text{PO}_4$  or  $(\text{NH}_4)_2\text{HPO}_4$  than when applied as  $(\text{NH}_4)_2\text{SO}_4$  or  $\text{NH}_4\text{Cl}$ . Thus, the na-

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