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RESPONSE OF CROP PLANTS TO I AND Br

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Received for publication July 26, 1951

A previous contribution from this laboratory dealt with the I content of New rsey soils and plants (10). Although the research evidence indicates that I plications do not produce yield increases (2, 3, 4, 7, 8, 12, 13), some stimula- on has been reported (9, 15). Information on the effect of Br on plant growth very meager (3, 13). Lewis and Powers (8) found that Cl had an antagonistic fect upon I toxicity in corn. No information is available on similar antagonism tween I and Br, and little is known about the residual effects of I applications. The purposes of the present study were to determine whether tomatoes would spond to I or Br applications to the soils on which they were being grown; to termine the residual effects of such I applications, using buckwheat as a test op; and to investigate I-Cl and I-Br relationships in plants.

EXPERIMENTAL METHODS

To study the response of tomatoes to I application, nine New Jersey soils rying from 0.0 to 12.1 ppm. in total I were selected (11). The soils were col- cted from virgin areas, brought into the laboratory, air-dried, and screened.

Uniform weights of the soils were placed in 2-gallon ceramic pots, limed to ther pH 6.5 or 7.0 with $CaCO_3$, and treated with a 10-10-10 fertilizer equiva- nt to 1 ton an acre. N was supplied either as NH_4NO_3 or KNO_3, P as $a(H_2PO_4)_2 \cdot H_2O$, K either as KNO_3 or KCl, and I or B as the K salts. Mg, as e sulfate at the rate of 100 pounds MgO an acre, and $Na_2B_4O_7 \cdot 10H_2O$, $MnSO_4$, d $ZnSO_4$ at 20 pounds an acre each were added to all soils except the Lakewood, which each rate of application was reduced one half. In all cases, C. P. reagent lts were used. $CaCO_3$ and $Ca(H_2PO_4)_2 \cdot H_2O$ were applied in the dry state and e other salts in solution, and all were thoroughly mixed with the soil.

Specific treatments were in triplicate and consisted of: 1. Check, all K as NO_3; 2. One pound I an acre, remainder K as KNO_3; 3. Ten pounds I an acre, mainder K as KNO_3; 4. Ten pounds I an acre, remainder K as KCl; 5. Check, K supplied as KCl (Sassafras sandy loam only).

The soils were seeded to Rutgers tomatoes September 9, 1949. The plants re thinned later to two a pot and grown at optimum moisture levels by periodic ditions of water. They were harvested at the blossom stage December 15, 1949.

Buckwheat was seeded February 26, 1950, following a second fertilizer treat- nt at half the rates used in the initial I study. The plants were thinned to four pot. They were harvested April 3.

For the Br studies, five soils were selected, fertilized, and limed as in the I

[1] Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers iversity, the State University of New Jersey, department of soils.

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SOIL SCIENCE

VOLUME 73 | *February 1952* | NUMBER 2

Ref 7/26/1951

A NONSTATIONARY METHOD FOR DETERMINING THERMAL CONDUCTIVITY OF SOIL IN SITU

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Received for publication June 22, 1951

An accurate determination of the thermal conductivity of soils *in situ* is important in soil physics, meteorology, and agricultural and civil engineering. The only method that could be found in literature is the one developed by Albrecht (1) and applied by Franssila (4) and Bracht (2). This method is based on the theory of steady flow of heat.

Because the transport of heat in a moist porous material is accompanied by distillation of water vapor, the author has argued elsewhere (7) that a nonstationary method and the use of small temperature gradients are preferable in measuring the thermal conductivities of soils. Such a method has been developed by Van der Held and Van Drunen (5) for determining the thermal conductivity of liquids. Earlier work on this method was that of Stålhane and Pyk (6) and of Weishaupt (8). The method has already been applied by Van Dorssen (3) to the measurement of thermal conductivity of sand at low moisture contents in the laboratory.

This article discusses the construction of a cylindrical element that can be placed in the soil to measure its thermal conductivity by the aforementioned method and presents some of the results obtained. An important feature is the small diameter of the cylinders, which makes it possible to introduce them into the soil without markedly disturbing the natural structure.

PRINCIPLE OF THE METHOD

The thermal conductivity of the material under investigation is measured by introducing a long electrically heated wire in the (homogeneous) material, switching on the heating current in this wire, and measuring the rise of temperature with a thermocouple somewhere near the middle of the wire.

For a linear heat-source of infinite length, the rise of temperature (θ) at radial distance r from the source is represented by:

$$\theta = (q/4\pi\lambda)\ \{-Ei(-r^2/4at)\} \qquad (1)$$

[1] The author is indebted to W. R. van Wijk for his interest in this work and for useful suggestions, to E. M. F. van der Held for his kindness in showing the thermal conductivity measurements in progress at his laboratory, and to L. Admiraal for his help with the construction of the elements and the carrying out of the measurements.

study and were treated with KBr at rates equivalent to 50 and 100 pounds Br an acre. All treatments were in triplicate. Pots were seeded to Rutgers tomatoes on June 28, and the plants were thinned to one a pot when 2 inches high. They were harvested August 24, 1950, in the preblooming stage.

In the study of I-Cl and I-Br relationships in plants, solution culture techniques (15) were employed. A standard nutrient solution of the following composition was used in all tests:

KH_2PO_4	0.0023 *M*	B as boric acid	0.25 ppm.
$(NH_4)_2SO_4$	0.0007 *M*	Mn as sulfate	0.25 ppm.
$Ca(NO_3)_2$	0.0045 *M*	Zn as sulfate	0.25 ppm.
$MgSO_4$	0.0023 *M*	Fe as sulfate	1.00 ppm.
K_2SO_4[2]	0.0020 *M*		

The standard nutrient solution had a pH value of 4.5. All cultures were renewed twice weekly.

Rutgers tomatoes were used in studying I-Cl relationships. They were grown in solution cultures containing 0, 0.5, and 5 ppm. I, respectively, in presence and absence of chlorine. The I-Cl ratio was 1:15. Treatments were in duplicate. Seeds were placed in sand on October 21, 1949. Later, two uniform seedlings were selected and placed in 1-gallon solution jars. Plants were harvested on January 6, 1950, at the flowering stage and fractionated into leaflets, petioles, stems, and roots.

Similarly, I-Br relationships were investigated, the tomatoes being grown in solution cultures containing 0, 1, 5, 10, and 20 ppm. Br in presence and absence of I. Treatments were in triplicate. Seeds were placed in sand on March 24, 1950, and small seedlings were transplanted to 1-gallon solution culture jars on April 20. Br treatments were started on April 27. The plants were harvested on May 2[illegible].

Immediately after the harvest of each crop, the samples were oven-dried at approximately 70° C. in a forced draft air oven, weighed, ground in a small Wiley mill, and stored. The samples were again dried at 70° C. prior to analysis.

I was estimated by the chromic-sulfuric acid digestion method of Houston (6); Br by a modification of Hibbard's procedure (5); and Cl was titrated electrometrically according to the Piper method (11) and with the apparatus designed by Best (1).

RESULTS AND DISCUSSION

Response of tomatoes to I applications

No differences in germination of tomatoes were noted because of the I treatments. Seedlings growing on Lakewood sand, which received I at the 10-pounds-an-acre rate, exhibited signs of poor growth. Toxicity symptoms were more pronounced when K was supplied as the chloride. Retardation of growth was observed initially on Copake loam with 10 pounds I when K was supplied as KCl, but at harvest time these differences had disappeared. No other visual differences were observed because of the treatments.

[2] The K_2SO_4 was varied as necessary to make allowance for the K supplied as KI, KCl, or KBr.

Yields of tomato tops were not increased with the 1-pound-an-acre rate of application of I. The 10-pound rate was toxic to plants growing on the Norton, Lakewood, Lawrenceville, and Washington soils (table 1). Yields were lower when K was supplied as the chloride. For example, when I was applied to the Lakewood soil at the 10-pound rate and K as the nitrate, the yield of dry matter was 11.8 gm. a pot, whereas when the K was supplied as the chloride, the yield was only 2.8 gm.

Cl toxicity was ruled out because the rate of application was equivalent to only 150 pounds Cl an acre, and it is known that 1500 ppm. Cl in solution culture does not affect tomatoes adversely. Why Cl applied in conjunction with I should increase toxicity is not clear.

TABLE 1

Dry weight yields and I and Cl content of tomato tops

	DRY WEIGHT†					I CONTENT					Cl CONTENT				
I added*	0	1	10	10	0	0	1	10	10	0	0	1	10	10	0
Form of K	KNO_3	KNO_3	KNO_3	KCl	KCl	KNO_3	KNO_3	KNO_3	KCl	KCl	KNO_3	KNO_3	KNO_3	KCl	KCl
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*
Lakewood sand	22.2	20.0	11.8	2.8	—	0.20	1.20	61.20	73.65	—	720	820	1,640	9,030	—
Copake loam	29.8	29.2	27.4	28.8	—	0.30	0.85	8.90	11.65	—	820	820	920	13,200	—
Squires loam	21.6	22.2	22.1	20.7	—	0.50	0.50	3.20	3.40	—	720	1,130	820	10,500	—
Washington loam	5.8	5.9	2.8	2.0	—	0.60	0.60	2.35	2.75	—	2,050	1,640	2,460	9,750	—
Hoosic stony loam	20.9	21.4	23.5	22.1	—	0.60	0.65	4.90	5.30	—	1,230	1,030	1,130	6,770	—
Sassafras sandy loam	30.6	30.4	31.2	31.0	32.0	0.65	0.50	11.70	77.90	0.50	600	620	590	11,420	13,000
Norton silt loam	26.2	23.0	19.6	15.8	—	0.80	0.80	1.25	1.70	—	3,290	3,180	3,280	6,050	—
Collington sandy loam	6.4	7.1	8.0	6.5	—	0.85	1.00	4.00	5.30	—	2,460	2,150	1,850	7,700	—
Lawrenceville silt loam	12.1	10.3	8.5	3.3	—	1.05	1.80	6.55	8.05	—	2,360	1,950	2,150	8,620	—

* In pounds per acre, as KI.
† Average yields of triplicate treatments.

The I content of tomato plants grown on the untreated soils varied considerably and ranged from 0.20 ppm. on the Lakewood to 1.05 ppm. on the Lawrenceville soil (table 1). Addition of I at the rate of 1 pound an acre generally increased the I content of the plants. No increases in I content were obtained with plants grown on the Squires, Washington, and Norton soils, but large increases resulted on the Lakewood, Copake, and Lawrenceville soils. Very slight effect was noted on the Hoosic soil. At the 10-pound rate of application of I, large increases in I content of tomato tops were noted on all soils. The highest I content, 61.2 ppm., occurred on the Lakewood and the lowest, 1.25 ppm., on the Norton soil.

When all K was supplied as the chloride, I uptake was increased. These results are in contrast to those of Lewis and Powers (8) with corn. Why the presence of Cl should increase I uptake by tomatoes is not clear.

Whether Cl uptake is affected by I applications cannot be answered. The Cl

content of tomatoes varied with the nature of the soils, and ranged from 600 to 3,290 ppm. on the no-I treatments when K was supplied as KNO_3 (table 1). Addition of 150 pounds Cl an acre as KCl markedly increased the Cl content of the plants.

Variations existed in the I content of fractions of tomato plants grown on Sassafras sandy loam at different levels of I (table 2). When I was not supplied, the I content of the fractions decreased in the following order: roots, upper leaves, lower leaves, lower stems, and upper stems. When I was applied at the 10-pound-an-acre rate in conjunction with K supplied as the chloride, the order of decreasing I content was: lower leaves, lower stems, roots, upper leaves, and upper stems. When comparison is made of the I content of the various fractions of tomato plants grown at the I applications of 10 pounds an acre and K supplied as the chloride or nitrate, the relative distribution of I was found to be the same,

TABLE 2

Distribution of I and Cl in various fractions of tomatoes grown on Sassafras sandy loam

TREATMENT		I CONTENT					Cl CONTENT				
I added*	Form of K	Upper Leaves	Lower Leaves	Upper Stems	Lower Stems	Roots	Upper Leaves	Lower Leaves	Upper Stems	Lower Stems	Roots
lb./A.		*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*
0	KNO_3	0.95	0.70	0.45	0.50	3.25	820	510	1,130	410	31(
1	KNO_3	0.65	0.90	0.35	0.25	1.55	925	615	1,330	310	41(
10	KNO_3	14.40	90.00	4.55	14.80	23.00	720	410	1,230	410	31(
10	KCl	24.40	153.40	14.40	48.70	30.60	6,360	10,260	14,990	13,240	7,29(
0	KCl	1.00	0.75	0.60	0.15	1.30	6,980	13,750	15,290	13,750	6,67(

* I added as KI.

but the actual amount of I found in the fractions was higher when K was sup plied as the chloride.

Residual effects of I applications

Buckwheat yields were not increased by I applications except on the Norto soil, and these may be considered to be well within experimental error (table 3 It will be recalled that I at all levels on this soil initially were toxic to tomatoe: Buckwheat on the Lakewood and Lawrenceville soils exhibited toxicity simila to that noted with tomatoes. Buckwheat yields were reduced on the Hoosi although tomatoes had not exhibited symptoms of toxicity when previous grown on this soil. Yields of buckwheat from Copake, Collington, Squires, ar Sassafras soils were not significantly affected by previous I treatments. In mo cases, yield decreases from I applications at the 10-pound rate, with K added KCl, were more pronounced than when K was added as KNO_3. Cl seemed increase rather than counteract I toxicity.

Residual effects from the initial I treatment at the rate of 1 pound an ac were still reflected in the I content of buckwheat grown on all except the Norto Copake, and Washington soils (table 3). On the Sassafras soil, the I content i creased from 0.85 ppm. to 1.00 and 2.85 ppm. as the initial I application w

increased from 0 to 1 and 10 pounds an acre. The residual effect from the 10-pound application was more pronounced than that from the 1-pound rate and also was greater on the Sassafras, Collington, Squires, Copake, and Lakewood

TABLE 3

Dry weight yields and I and Cl content of buckwheat grown as residual crop

	DRY WEIGHT†					I CONTENT					Cl CONTENT				
I added*	0	1	10	10	0	0	1	10	10	0	0	1	10	10	10
Form of K	KNO_3	KNO_3	KNO_3	KCl	KCl	KNO_3	KNO_3	KNO_3	KCl	KCl	KNO_3	KNO_3	KNO_3	KNO_3	KCl
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*		*ppm.*	*ppm.*
Lakewood sand	4.1	3.9	3.4	2.7	—										
Leaves						1.30	2.10	12.35	10.30	—	1,330	1,330	1,330	4,920	—
Stems						1.05	1.00	9.45	11.55	—	1,950	1,540	1,740	8,930	—
Copake loam	3.8	3.5	3.6	3.4	—	0.75	0.80	6.75	9.45	—	820	720	820	11,300	—
Squires loam	3.2	3.0	2.8	2.8	—	0.65	1.05	2.40	6.00	—	1,020	1,130	1,230	9,240	—
Washington loam	2.5	1.4	2.3	2.1	—	0.80	0.80	1.50	1.20	—	1,130	1,440	1,540	6,460	—
Mosic stony loam	3.0	2.5	2.3	1.7	—	0.95	0.65	6.75	9.45	—	820	1,030	1,130	6,460	—
Sassafras sandy loam	3.2	3.0	2.9	3.1	3.1‡	0.85	1.00	2.85	3.85	0.90	920	1,130	1,030	9,450	7,700
Norton silt loam	3.3	3.5	3.6	2.8	—	0.65	0.70	1.55	1.40	—	1,850	2,050	2,050	4,720	—
Collington sandy loam	2.1	2.2	1.8	1.8	—	1.05	1.25	8.75	11.35	—	1,540	1,740	1,740	7,080	—
Lawrenceville silt loam	2.8	2.1	1.7	1.5	—	1.00	1.50	3.40	3.40	—	1,640	1,330	1,640	3,800	—

* Pounds an acre, as KI, to tomatoes harvested previously.
† Average yields from triplicate pots.
‡ Average 2 pots.

TABLE 4

Dry weight yield of Rutgers tomatoes as affected by Br applications

Br added*	DRY WEIGHTS†		
	0	50	100
	gm.	*gm.*	*gm.*
Annandale loam	12.4	12.0	11.5
Norton silt loam	5.9	5.0	5.2
Sassafras sandy loam	9.9	10.3	10.5
Squires loam	9.4	10.1	10.7
Collington loam	9.6	10.4	8.7

* Pounds an acre, as KBr.
† Average yield of triplicate pots.

than on the Norton, Lawrenceville, and Washington soils. The effect of Cl on the I uptake was still reflected in the second crop on all soils. The Cl content of the buckwheat was unaffected by the previous I applications (table 3).

Response of tomatoes to Br

No visual differences were noted in tomatoes grown on the five soils following application of Br at rates of 50 and 100 pounds an acre. Slight increases in yield

were noted on the Sassafras and Squires soils (table 4). A slight increase was also noted on the Collington soil at the rate of 50 pounds an acre. The increases were not significant. A slight reduction of yield was noted on both the Annandale and Norton soils, but this was probably not significant.

TABLE 5

Dry weight yields and I, Cl, and Br content of leaflets, stems, and roots of tomatoes

TREATMENT		DRY WEIGHTS*			I CONTENT			Cl CONTENT			Br CONTENT		
I	Br	Tops	Roots	Total	Leaflets	Stems	Roots	Leaflets	Stems	Roots	Leaflets	Stems	Roots
ppm.	*ppm.*	*gm.*	*gm.*	*gm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*
0	0	15.7	3.4	19.1	1.55	0.90	3.80	410	410	410	40	—	—
0	0	12.9	3.1	16.0	533.90	603.00	275.10	410	410	510	<4	—	—
2	1	14.9	3.0	17.9	651.70	575.50	313.20	720	620	510	<4	—	—
2	5	13.7	2.9	16.6	717.30	433.80	275.10	820	1030	620	<4	—	—
2	10	16.1	3.4	19.5	647.50	581.90	317.40	1440	2050	1750	<4	—	—
2	20	12.4	3.1	15.5	760.70	558.60	323.75	2050	3490	2050	<4	—	—
0	1	11.8	2.6	14.4	2.70	0.40	5.40	615	720	620	1440	—	—
0	5	16.6	2.8	19.4	2.10	1.60	4.75	1030	1540	1030	850	—	—
0	10	15.1	3.3	18.4	2.05	1.25	3.35	1540	2670	1440	1450	—	—
0	20	18.8	4.1	22.9	1.80	1.25	2.40	2670	5130	2460	2825	6320	2100

* Average of triplicate pots.

TABLE 6

Dry weight yields and I and Cl contents of leaves, petioles, stems, and roots of tomatoes

TREATMENT		DRY WEIGHTS*			I CONTENT				Cl CONTENT			
I	Cl	Tops	Roots	Total	Leave	Petioles	Stems	Roots	Leaves	Petioles	Stems	Roots
ppm.	*ppm.*	*gm.*	*gm.*	*gm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*	*ppm.*
0	0	17.0	1.7	18.7	2.80	2.75	1.50	10.60	720	920	510	310
0	7.5	22.0	1.9	23.9	2.95	2.40	2.25	6.40	2,050	6,880	7,800	3,800
0	75.0	21.6	2.3	23.9	3.55	6.15	2.40	7.50	3,900	14,880	16,620	8,620
0.5	0	16.4	1.6	18.0	255.20	302.00	216.00	380.00	510	720	510	510
5.0	0	9.2	1.5	10.7	744.80	1,523.50	1,555.00	603.00	920	1,640	820	1,130
0.5	7.5	18.0	2.0	20.0	338.00	281.20	214.00	338.00	1,330	3,900	4,310	2,770
5.0	75.0	6.3	0.8	7.1	952.20	2,190.00	1,785.00	687.00	4,510	14,370	—	5,390

* Average yield of duplicate pots.

I-Cl and I-Br relationships in tomatoes

Observations made on tomatoes grown in solution cultures at varying I and Cl levels showed that 5 ppm. I produced severe toxicity effects 12 days after the treatments were started. The leaves were mottled, lighter green areas appearing between the veins, while the areas immediately around the veins remained a healthy dark green. Some leaves showed a few necrotic spots along the edges and tips, while others were slightly curled along the edges. The presence of Cl in the nutrient solution augmented these symptoms. Two parts per million I produced

only a slight mottling, whereas 0.5 ppm. had no visible effect. Plants that received 7.5 or 75 ppm. Cl in absence of I appeared to grow vigorously.

Cl at levels of 7.5 and 75 ppm. stimulated growth in absence of I. Some stimulation was also observed at the 7.5 ppm. Cl and 0.5 ppm. I levels, whereas 2 ppm. I proved somewhat toxic, and the 5 ppm. I markedly reduced growth (tables 5 and 6). In the latter case the toxicity was increased by the presence of 75 ppm. Cl.

Both the I and Cl contents of the plant fractions increased directly with the levels of these elements in solution (table 6). Generally, the I contents of the various plant fractions were increased by the addition of Cl. For example, the leaf portions of the plants receiving 5 ppm. I and no Cl, contained 744.8 ppm. I, whereas when Cl was present to the extent of 75 ppm., the I content was 952.2 ppm. The effects of I on Cl uptake were variable.

Br additions up to 20 ppm. did not affect the growth of the plant (table 5). In a manner similar to I, the Br content of tomato leaflets generally increased as the Br level in the nutrient solution was raised. Increasing Br levels in the substrate did not affect the I content of tomatoes. Although Cl-Br relationships were not a part of this study, the data show that an increase in Br in the substrate tended to increase Cl uptake.

SUMMARY

Applications of KI were made to nine New Jersey soils, and tomatoes were used to test the effect of the added I. Residual effects of the I additions were studied on buckwheat as a test crop. A preliminary test was made of the effect of Br additions. I-Cl and I-Br relationships in tomatoes were studied by use of solution-culture procedures.

Yield responses were not obtained with tomatoes on any of these soils when I was applied at rates of 1 and 10 pounds an acre. I at the 1-pound rate had no effect on the growth of tomatoes on the soils, but at the 10-pound rate it was toxic to tomatoes on the Norton, Lawrenceville, Washington, and Lakewood soils.

Addition of Cl as KCl tended to increase toxicity symptoms of I in soil cultures and also to increase I uptake by both tomatoes and buckwheat.

Residual effects of the initial I applications were observed on the yield and I content of buckwheat from several soils.

Yield responses from Br applications at rates of 50 and 100 pounds an acre were not obtained on five typical New Jersey soils.

I-Cl antagonism was not observed in tomatoes in either solution tests or soil tests.

I uptake was increased by addition of Cl, but no effect of I on Cl uptake was observed.

I-Br antagonism was not observed in solution cultures, although Br seemed to increase Cl uptake.

The Br content of leaflets of tomatoes grown in the tests ranged from less than 4 ppm. to 2,825 ppm. depending on the amount of Br present in the nutrient solution.

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