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INFLUENCE OF ORGANIC MATTER ON THE
AVAILABILITY OF CERTAIN ELEMENTS TO
BARLEY SEEDLINGS GROWN BY A
MODIFIED NEUBAUER METHOD

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Fig. 1. Effects of organic matter concentration and incubation time before cropping on the average yields of barley seedlings.

Fig. 2. Average concentrations of N, P, Al, and Si in barley seedlings.

Fig. 3. Average concentrations of Na, K, Mg, Ca, Sr, and Ba in barley seedlings.

Fig. 4. Average concentrations of B, Cu, Zn, Fe, Mn, and Mo in barley seedlings.

Fig. 5. Average Cs^{137} contents of barley seedlings in relation to incubation time before cropping.

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SUMMARY

The influence of organic matter on the availability of 17 elements (Na, K, Cs¹³⁷, Mg, Ca, Sr, Ba, N, P, B, Cu, Zn, Fe, Mn, Mo, Al, and Si) to barley seedlings grown by a modified Neubauer technique was determined. Three different soils that were treated with dry ground mustard spinach leaves (1 g/100 g soil) and incubated for various lengths of time (0, 1, 2, 5, 9, 13, and 17 weeks) in moist condition before cropping were used for this study.

The addition of organic matter to the soils increased the plant yields. The average N and K concentrations were consistently increased in the plants grown in soils with added organic matter. The average concentration of B, P, Na, Mg, Sr, Ba, and Si were almost consistently decreased in the plants. The average contents of Cu, Zn, Fe, Mn, Mo, Ca, and Al varied with the soil types and precropping incubation time. The average Cs¹³⁷ contents of the plants were reduced considerably by the addition of organic matter to the soils. The reduction of Cs¹³⁷ contents ranged from 29 to 75 per-cent, depending on the pre-cropping incubation time and soil type. The main factors causing this reduction were considered to be microbial immobilization, ion antagonism

by K, "carbohydrate dilution", and the state of decomposition and the kind of organic matter added to the soils.

INTRODUCTION

It is well recognized that soil organic matter, together with associated microorganisms, play an important role in the availability of mineral ions to plants. In addition to those released by weathering of inorganic materials, the breakdown of organic matter in the soil releases a number of different elements. The released elements may or may not be readily available to plant roots because of the influence of soil microorganisms and colloids. A number of reviews of soil organic matter are available in the literature^{5 6 9 19 24 28 35 45}.

This paper shows the influence of organic matter on the availability of 17 elements (Na, K, Cs¹³⁷, Mg, Ca, Sr, Ba, N, P, B, Cu, Zn, Fe, Mn, Mo, Al, and Si) to barley seedlings grown by a modified Neubauer technique. A particular emphasis is placed on the availability of Cs¹³⁷ because of our interest in the behavior of radionuclides, particularly long-lived fission products, that occur in soils as contaminants in tracer amounts.

MATERIALS AND METHODS

The soils used in this investigation were Hanford sandy loam, Vina loam, and Aiken clay loam. Their chemical and physical properties are shown in Table 1.

The soils were prepared for plant growth as follows. Under treatment I, 100-g aliquots of soils placed in Pyrex deep pie

dishes (painted with an opaque plastic base paint) were contaminated with carrier-free Cs^{137} (118 dis/sec/g) in 6.5 ml volumes of aqueous solution, mixed thoroughly and allowed to air dry. The air-dried contaminated soils were then brought to field capacity with distilled water and incubated in moist condition at room temperature (23°C) for various lengths of time (0, 1, 2, 5, 9, 13, and 17 weeks) before cropping. Under treatment II, the soils were contaminated in the same manner as above. Then one g of dried uncontaminated mustard spinach leaves ground in a Wiley mill to pass through a 40-mesh screen was added to each dish before adding the water. The soils of treatment III were prepared by adding one g of dried Cs^{137} contaminated, ground mustard spinach leaves, whose radioactivity was 1.18×10^4 dis/sec/g. Note that the application level of Cs^{137} was the same whether it was in the solution or the organic form. All treatments were replicated 5 times. The Cs^{137} contaminated and uncontaminated mustard spinach were obtained by growing the plants in a modified Hoagland's nutrient solution with and without Cs^{137} tracer. The average chemical composition of the mustard spinach leaves applied to the soils is shown in Table 2. Only one set of data is given, because except for Cs^{137} , the leaf elemental contents were not significantly different.

During the incubation periods, the water that was lost by evaporation was replenished by weight twice a week. The different incubation treatments were started at the appropriate times, so that all of the treated soils were cropped simultaneously

in the same plant growth chamber. The soils were cropped by the Neubauer Technique²⁶ modified to use barley seedlings (*Hordeum vulgare*, va. Atlas) instead of rye seedlings. The cropping period was 22 days.

All Cs¹³⁷ radio-assays were done in duplicate with a low background gas-flow detector system (150 mg/cm² mica window) having an efficiency of 16 per cent for Cs¹³⁷. Appropriate corrections for counting efficiency, self-absorption and decay were made on all samples. The N analyses were performed with Coleman Nitrogen Analyzer II (Model 29A) on 0.1 g aliquots of pulverized plant material. The remaining elements (Na, K, Mg, Ca, Sr, Ba, P, B, Cu, Zn, Fe, Mn, Mo, Al and Si) were determined with the use of 1.5 meter, direct reading emission spectrometer (Applied Research Laboratories).

RESULTS AND DISCUSSION

Figure 1 shows the average yields of the barley tops produced under the different treatments. The yields of the plants grown in the soils receiving no additional organic matter (treatment I) were in the following order: Aiken c.l. < Hanford s.l. < Vina l. The yield differences between these soils were statistically significant at the 1 per cent level. For any given soil, the yields of the treatment I plants were significantly (1 per cent level) lower than those of the treatment II or III plants, which were grown in soils treated with additional organic matter. Thus, the application of organic matter to the soils had a beneficial

effect on plant growth.

A comparison of plant yields between treatments II and III for Hanford s.l. or Vina l. showed no difference at the 5 per cent level of significance. For some undetermined reason, the same comparison for Aiken c.l. showed that the treatment II plant yields were significantly lower than that of treatment III under 5-, 9-, and 13-week pre-cropping incubation conditions. In any case, among the 3 soils treated with organic matter, Vina l. showed significantly (1 per cent level) greater plant yields than Hanford s.l. or Aiken c.l. With the exceptions mentioned above, the plant yields for the organic matter treated Aiken c.l. were not significantly different from that for Hanford s.l.

When simple salt fertilizers are added to soils the increases of plant yields may be ascribed to the increased availability of one limiting element that was applied. However, the increases of plant yields caused by the application of organic matter are not readily ascribable to the increased availability of a particular element, since the availability of several elements may be increased. The influences of the organic matter application on the elemental contents of the barley seedlings are shown in figures 2, 3, and 4. The average N and K contents were consistently increased, irrespective of soil type or pre-cropping incubation time. (The data for treatment III only are compared with those of treatment I, since the differences between treatments

II and III were very small, if there were any differences at all). The average contents of B, P, Na, Mg, Sr, Ba, and Si were almost consistently decreased. The average contents of Cu, Zn, Fe, Mn, Mo, Ca, and Al appeared to vary considerably with the soil type and pre-cropping incubation time. As indicated by the relatively large standard deviation, the variability of the majority of the latter group of elements within any given treatment was greater than those of other groups of elements. A summary of the statistical test of difference (5 per cent level of significance) between the elemental concentrations of the treatment-I and -III plants is given in Table 3.

The increased availability of the first group of elements (N and K) is ascribed to their release from the decomposing organic matter over and above that immobilized by microorganisms. Of the 2 elements in this group, N very likely was the more important one in increasing the plant yields. Potassium is considered to be of lesser importance, because it was not limiting. Its extractable form (Table 1) was sufficiently high in the soils even before the application of organic matter. The degree of K saturation of the soil exchange complexes ranged from 3.3 to 9.5 per cent.

The reduced availability of the second group of elements (B, P, Na, Mg, Sr, Ba, and Si) to plants is considered to be due primarily to microbial immobilization. This implies that the available concentrations of this group of elements were not

sufficiently high to overcome the effect of microbial immobilization. Microbial immobilization is surmised from the fact that the microbial population in the soil increases greatly upon the addition of undecomposed organic matter³⁹. In accumulating the available ions, the microorganisms have an overwhelming advantage, because they are at the very site at which the decomposition of organic matter occurs and available ions are released. Because of their tremendous number and their minute size, it is reasonable to assume that they also present much larger surface within a given soil bulk from which ions are adsorbed and/or absorbed. Microorganisms also produce metabolically active substances that can influence the rate of ion uptake by the plants²⁹. Barber² has reviewed the effects of microorganisms on the absorption of ions by plants.

It was noted above that the third group of elements (Cu, Zn, Fe, Mn, Mo, Ca, and Al) showed considerable variability. Perhaps, the notable elements of this group are Mn and Mo. The average Mn contents of the plants grown in Aiken c.l. with added organic matter were consistently decreased, whereas they varied with the pre-cropping incubation time of the other soils. The average plant contents of Mo were consistently increased with Hanford s.l. and decreased with Aiken c.l. With Vina l., its plant contents varied with pre-cropping incubation time. In general, the variable behavior of this group of elements is not readily explainable. Part of the variability could be due

to microbial activity. A certain amount of microbial immobilization must certainly occur since all elements in this group, except Al, are essential nutrient elements. Other factors that could be involved are the plant absorption characteristics of the elements and the interaction of the elements with the soil. The Ca data perhaps illustrate the latter factor in operation. The Ca uptake by the plants was less from Vina l. than from Hanford s.l. or Aiken c.l., even though its extractable Ca (Table 1) was greater than that for the latter soils. This effect could be explained, at least in part, by the degree of Ca saturation in the exchange complex of the soils and the predominant clay minerals in the soils. A number of investigators have shown that cation availability to plants is affected by the nature of the exchange materials in soils and their degree of cation saturation^{4 7 11 12 30 31 42}. The change of soil pH as a result of organic matter mineralization could also have an effect. The data of Wallace et al.⁴⁴ show that the addition of organic matter could increase the soil pH by 0.5 unit or more. This, however, should be interpreted in the light of the amount of organic matter added and the kind of soil used, since different soils have different buffer capacity.

Figure 5 shows that the average Cs¹³⁷ contents of the barley seedlings were reduced considerably by the addition of organic matter to the soils. Depending on the pre-cropping incubation time, the percentage reduction of the average contents ranged

from 29 to 47, 52 to 59, and 34 to 75 for Hanford s.l., Vina 1. and Aiken c.l., respectively. With Hanford s.l. and Vina 1., the difference of the average Cs^{137} contents between treatments II and III were insignificant. With Aiken c.l., the average Cs^{137} contents are shown to be definitely reduced under treatment III for the 5-, 9-, and 13- week pre-cropping incubation periods for an undetermined reason. A summary of the statistical test of difference (5 per cent level) of Cs^{137} contents of the barley seedlings as influenced by organic matter treatment, incubation time, and interaction is given in Table 4. Obviously, there were several significant effects depending on the soil. In any case, the important point is that the application of organic matter to the soils significantly reduced the Cs^{137} uptake by plants.

At least three factors played some role in reducing the Cs^{137} uptake by the plants. One factor was certainly microbial immobilization mentioned above. Since Cs^{137} occurred only in tracer quantity in the soils, the ratio of the number of Cs^{137} ions to the number of microbial cells was relatively very small. Thus, microbial immobilization should be quite effective. Ion antagonism by K was very likely another factor, because as indicated by appreciably increased K uptake by the plants (figure 3), the available K in the soils was increased. This resulted in the marked decrease of Cs^{137}/K atom ratios in the plants (Table 5). The depressive effect of K on Cs uptake by plants has been well

established by solution culture studies^{1 8 14 22 25 33 34 37} and soil culture experiments^{15-18 27 32 40 41}. Another factor may be "carbohydrate dilution," since plant growth was increased by the addition of organic matter (figure 1). This factor probably functioned also to some extent in causing the reduction of the uptake of several stable elements mentioned above. It has been reported that extractable Ca in the soil has a depressing effect on the accumulation of Cs¹³⁷ in the plant¹⁶. In the present experiment, the effect of Ca appeared to have varied, since the available Ca was reduced in certain cases and increased in others (figure 3).

GENERAL DISCUSSION

Barber³ found that Cs¹³⁷ uptake by ryegrass was greater from soils that were higher in organic matter content, and has pointed out that when organic matter is responsible for a large fraction of the total exchange capacity of the soil, the adsorption and subsequent fixation of Cs¹³⁷ on the clay minerals are much reduced. Part of this effect may be explained by the fact that organic matter could be adsorbed in the interlayers of the clay minerals^{13 20 21 23 36 43}. The adsorption of organic matter in effect tends to reduce the fixation of Cs¹³⁷ by blocking action. Another factor playing a role here may be the exchangeable K. Eagle¹⁰ has shown that the greater the organic matter content of the soil the higher the level of exchangeable K. This latter effect was also shown in our recent work³⁸.

Consequently, the competitive effect of exchangeable K may work in conjunction with organic matter adsorption in reducing Cs¹³⁷ fixation. The high availability of K reduces the Cs¹³⁷ fixation on the soil clay minerals. This in turn increases the Cs¹³⁷ availability to plant roots. However, the high availability of K also increases the competitive action of K on Cs¹³⁷ uptake by plant roots. Thus, the Cs¹³⁷ absorbed by the plants is the net result of opposing effects.

The difference between Barber's results³ and the results of the present experiment, which showed reductions of Cs¹³⁷ uptake by the plants grown in soils with added organic matter, suggests that there were influencing factors in addition to those discussed above. The important ones of these may be the state of decomposition and the kind of organic matter added to the soils. These factors determine the amount of different kinds of microorganisms that can absorb the tracer Cs¹³⁷. In Barber's experiment³, the soils, having received no fresh added organic matter, probably consisted primarily of humus and products of advanced decomposition of organic residues and products resynthesized by microorganisms. The soils of the present experiment contained these substances and the partially decomposed plant material that was added. Under the latter condition, there would be a flush of growth of microbial population, which would increase the amount of microbial immobilization of Cs¹³⁷.

The application of organic matter to the soils used was in general beneficial in that the plant yields were increased.

From the data available, it is difficult to state definitely which element had the greatest effect in causing the yield increases. However, it is surmised that N had the greatest effect. In other words, the organic material added probably was important primarily as a source of N.

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Table 1

Chemical and physical properties of the soils used.

Properties		Soil		
		Hanford s.l.	Vina l.	Aiken c.l.
pH (1:1 suspension)		6.60	6.55	6.00
Organic matter	%	1.99	0.63	2.72
Cation exchange capacity	me/100g	7.60	21.33	24.12
Extractable cations*				
Na	me/100g	0.21	0.10	0.08
K	me/100g	0.72	1.19	0.80
Mg	me/100g	1.40	5.63	2.36
Ca	me/100g	5.23	11.27	8.19
Predominant clay mineral**		I	MK	K
Particle size distribution				
sand		66.08	52.19	34.62
silt		26.54	34.31	39.28
clay		7.38	13.50	26.10

*Extractable with neutral normal ammonium acetate.

**I = illite; MK = montmorillonite and kaolinite; K = kaolinite.

Table 2

Average elemental composition of dry, ground mustard spinach leaves applied to the experimental soils.*

Element	mg/g	Element	μg/g	Element	μg/g
N	64.20 (1.50)	Na	98.20 (7.62)	Mn	111.60 (3.26)
P	6.54 (0.36)	Zn	109.20 (9.30)	B	25.10 (0.80)
K	48.26 (5.36)	Cu	7.13 (0.51)	Mo	7.17 (0.74)
Ca	18.40 (0.77)	Fe	29.70 (2.09)	Sr	1.23 (0.12)
Mg	4.43 (0.62)				

* Values within the parentheses represent one standard deviation.

Table 3

Summary of the statistical test of difference (5 per cent level of significance) between the elemental concentrations of the treatment-I and -III plants.

Group No.	Soil		
	Vina	Aiken	Hanford
I	Zn, Cu, Mo	Zn	Al, Fe
II	K, B, Mg, Al	K, Cu, Fe, Al Si, Mo, Sr	K, Zn, Cu, Mo Sr, N
III	P, Sr	Ca	Si
IV	Ca	none	P
V	Si, Ba	Mn, B	none
VI	Mn, N	N, P, Mg, Ba	Mg, Mn, B, Ba
VII	Fe	none	Ca

* I: No significant difference.

II: Organic matter treatment only significant.

III: Organic matter treatment and interaction significant.

IV: Incubation time and interaction significant.

V: Organic matter treatment and incubation time significant.

VI: Organic matter treatment, incubation time, and interaction significant.

VII: Interaction only significant.

Table 4

Summary of the statistical test of difference (5 per cent level of significance) of Cs¹³⁷ contents of barley seedlings as influenced by organic matter treatment, incubation time, and interaction.

Comparison	Soil*		
	Vina	Aiken	Hanford
Treat. I - Treat. II	A	B	C
Treat. I - Treat III	A	C	C
Treat. II - Treat. III	D	C	E

*A: Organic matter treatment only significant.

B: Organic matter treatment, incubation time, and interaction significant.

C: Organic matter and interaction significant.

D: Incubation time only significant.

E: No significant difference.

Table 5

$\text{Cs}^{137}/^{40}\text{K}$ atom ratios of barley seedlings grown in three soils that were incubated for various lengths of time before cropping.

Weeks of incubation before cropping	Aiken		Hanford		Vina	
	No O. M. Added	O. M. Added	No O. M. Added	O. M. Added	No O. M. Added	O. M. Added
0	250	139	183	76	140	48
1	304	198	211	90	161	56
2	451	223	250	94	163	60
5	465	210	241	91	195	61
9	494	210	235	97	180	52
13	490	160	176	84	141	51
17	555	194	211	97	156	52

O.M. = organic matter

Fig. 1. Effects of organic matter concentration and incubation time before cropping on the average yields of barley seedlings.

Fig. 2. Average concentrations of N, P, Al, and Si in barley

seedlings.

Fig. 3. Average concentrations of Na, K, Mg, Ca, Sr, and Ba in barley seedlings.

Fig. 4. Average concentrations of B, Cu, Zn, Fe, Mn, and Mo
in barley seedlings.

Fig. 5. Average Cs^{137} contents of barley seedlings in relation to incubation time before cropping.