0340

8/19/Ref 1973

Plant and Soil **40**, 637–646 (1974) Ms. 2309

PLANT RESPONSE TO MICRONUTRIENTS
I. UPTAKE, DISTRIBUTION AND TRANSLOCATION OF ZINC IN MAIZE AND BARLEY PLANTS

by B. R. SINGH and K. STEENBERG

Institute of Soil Science and
Isotope Laboratory Agricultural University of Norway

SUMMARY

The effects of zinc application on zinc uptake, distribution and translocation in maize and barley grown in zinc deficient soil with high pH and high calcium content were studied.

Zn^{65} content and uptake in roots, sheaths and blades of maize and barley plants increased significantly with increased levels of zinc application. The sheaths contained highest Zn^{65} content followed by roots and blades. The distribution of total zinc, however, differed from that of radioactive zinc. The roots had the highest zinc content, followed by sheaths and blades. The two species differed very little in zinc distribution patterns.

The autoradiographs of intact maize and barley plants showed that Zn^{65} was fairly evenly distributed in the main and auxiliary roots, but, there was a relatively higher concentration at the root-stem junction. The Zn^{65} concentration was higher in nodes than in internodes, and in young emerging leaves compared to older leaves.

INTRODUCTION

Zinc deficiency develops in plants grown on a variety of soils [7] particularly at high pH and high calcium content [1 12 14]. Previous investigations on the control of deficiency by zinc application [1 12 14] have not been concerned with the distribution and translocation of zinc in plants under these conditions.

The present work was, therefore, undertaken to determine the effect of zinc application on the uptake, distribution and translocation of zinc in maize and barley plants grown on soil which has been exposed to excessive liming.

9168

METHODS

A sandy loam soil containing 0.9 ppm of 0.2 N HCl-extractable zinc and with a pH value of 7.3 was selected for this study. Some of its physico-chemical properties are presented in Table 1. It was collected from a cultivated field in south-east Norway. The field had been subjected to excessive liming and therefore had a high pH compared to other local soils. Maize (*Zea mays*. L.) and barley (*Hordeum vulgare* v. Herta) plants were grown in the green house in 3 litre plastic pots containing 3 kg of soil. The experiment was a randomized block design with 3 replicates. The treatments were 0, 5, and 25 ppm of added zinc. Zinc in the form of $ZnSO_4.7H_2O$ was mixed with an active solution applied as 50 μc of Zn^{65} per pot giving the specific activities of 1560, 3.59 and 0.72 μc/mg of zinc at 0, 5 and 25 ppm of applied zinc, respectively. The solutions were thoroughly mixed into the soil by hand. Fertilizers were added at the rates of 120, 40 and 120 ppm of N, P, and K respectively. Six seeds of maize, or twelve seeds of barley, were sown in each pot and then thinned to 4 and 10 plants per pot, respectively, one week after germination. Soil moisture was maintained at approximately 50% of the water-holding capacity. Deficiency symptoms were recorded as they appeared.

TABLE 1

Physical and chemical properties of the soil used

Soil property	Soil used
pH	7.3
Texture	
Sand .....%	64
Silt .....%	32
Clay .....%	4
P-Al mg/100 g	13.0
K-Al mg/100 g	28.0
Ca-Al mg/100 g	124.0
Mg-Al mg/100 g	12.0
Mn ppm	2.3
Zn ppm	0.9
Cu ppm	2.6

The crops were harvested at 3 and 6 weeks after planting. The harvested plants were thoroughly rinsed in distilled water and divided into roots, stems + sheaths and leaf blades, and dried at 70°C. Stem + sheaths were mixed and analysed together. For convenience, this mixture is hereinafter referred to as sheaths.

The oven-dry weight of the plant parts were recorded. Plant samples were digested in nitric and perchloric acid mixture (2 : 1) and analysed for total

zinc by atomic absorption spectrometry. The activity of zinc in the digested plant material was determined by a NaI well scintillation spectrometer. Manganese, zinc and copper in the soil were determined in 0.2*N* HCl extract by atomic absorption spectrometry.

Zinc taken up by these plants was a mixture of active and inactive zinc of varying specific activities. The radioactive zinc (Zn^{65}) was calculated by comparing the measured activity in counts per minute with standards of known specific activities. The standards were prepared from the same active solution that had been previously used for mixing in the soil. All results were expressed on a dry matter basis. For autoradiographs the green intact plants of maize and barley harvested after 6 weeks growth were mounted on a folder and dried. The dried plants were placed on Kodak R P 54 X-ray film (35 × 43 cm) for an extended exposure time of 3 months, owing to the relatively low activity levels in the plants.

TABLE 2

The effect of zinc application on the total dry matter yield of maize and barley plants

Plant	Harvest	Zn rate ppm	Total dry matter yield (g/pot)			
			Roots	Sheaths	Blades	Total
Maize	Ist	0	0.92	1.45	1.90	4.27
		0a	1.04	1.28	2.04	4.36
		5a	1.15	1.80	2.82	5.77
		25a	1.04	1.60	2.78	5.42
	LSD		—	—	0.32	1.0
	IInd	0	3.64	5.74	6.55	15.93
		0a	3.12	4.27	4.71	12.10
		5a	2.97	5.43	9.11	17.51
		25a	3.06	6.15	9.32	18.53
	LSD		—	1.05	2.33	4.01
Barley	Ist	0	0.38	0.56	0.98	1.92
		0a	0.37	0.51	0.88	1.76
		5a	0.40	0.61	1.10	2.11
		25a	0.40	0.53	0.91	1.84
	LSD		—	—	—	0.24
	IInd	0	0.70	2.44	2.58	5.72
		0a	0.67	2.78	2.50	5.95
		5a	0.75	3.05	2.44	6.24
		25a	0.61	2.67	2.11	5.39
	LSD			0.24	0.24	

a = activity of Zn^{65} (50 μc/pot).

RESULTS

Applications of zinc eliminated zinc deficiency symptoms in maize plants. It significantly increased the dry matter yield for the first harvest in barley and for both harvests in maize (Table 2). Although barley plants apparently responded to zinc fertilization, typical zinc deficiency symptoms were not observed in barley. Dry matter yields of roots did not differ significantly among treatments, but significant differences were observed both in barley and in maize in yields of sheaths and blades. The dry matter yield of barley slightly decreased at 25 ppm level of zinc compared with 5 ppm level of zinc.

The concentration and uptake of Zn^{65} in roots, sheaths and blades of maize and barley increased significantly with increased level of zinc application in both the harvests. (Table 3, Fig. 1). The sheaths contained highest Zn^{65} content followed by roots and blades with the exception that at the 25 ppm level of zinc roots contained more radioactive zinc than sheaths. At 5 ppm level of zinc there were no appreciable differences in the Zn^{65} content of roots and blades but at the 25 ppm level of zinc differences were distinct. On an overall basis Zn^{65} content of maize plants was higher than in barley

TABLE 3

The effect of zinc application on Zn^{65} content and distribution in maize and barley plants

Zn rate	Plant	Zn^{65} content (ppm)					
		Ist harvest			IInd harvest		
		Roots	Sheaths	Blades	Roots	Sheaths	Blades
0a	Maize	0.06	0.13	0.05	0.07	0.14	0.05
5a		14.30	32.60	16.40	7.80	19.40	11.90
25a		202.80	85.10	39.60	48.00	73.00	29.10
LSD		128.80	12.32	5.16	3.58	6.97	2.25
0a	Barley	0.13	0.25	0.10	0.11	0.15	0.10
5a		27.96	51.50	25.90	22.10	40.30	19.50
25a		86.45	131.00	67.00	82.70	105.50	58.40
LSD		11.80	18.96	11.77	10.38	23.73	3.20

a = activity of Zn^{65} (50 μc/pot).

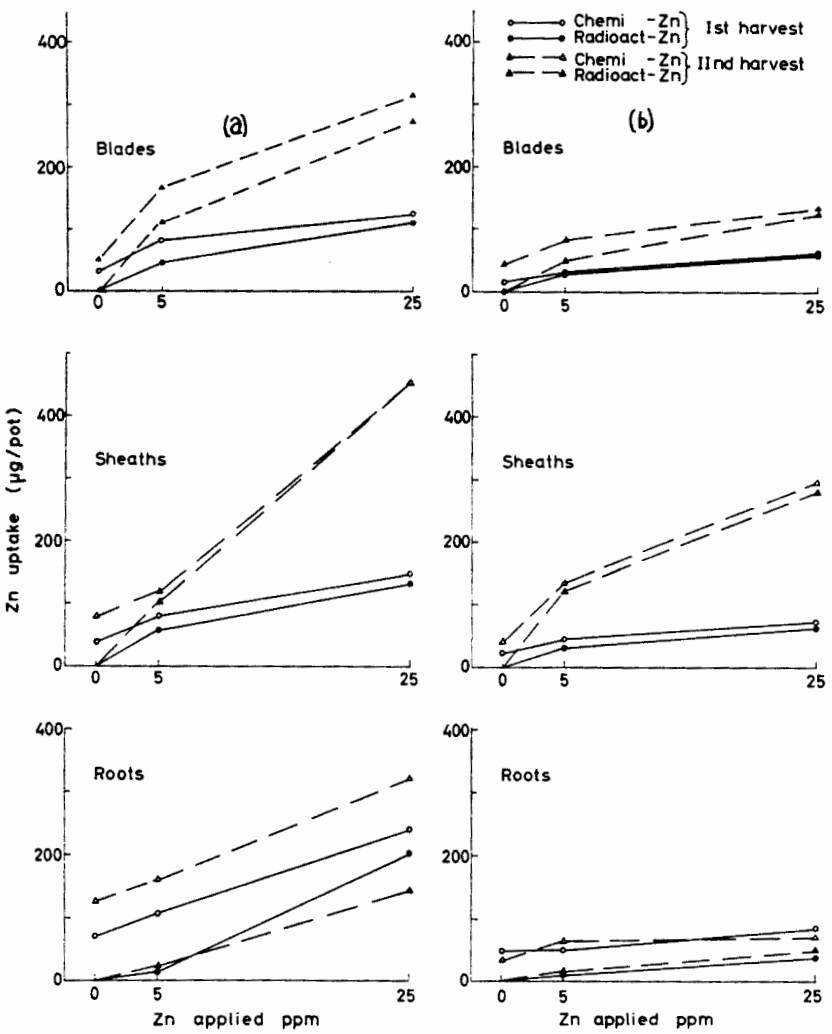

Fig. 1. Effect of zinc application on zinc uptake by (a) maize, and (b) barley plants.

plants as was the uptake of Zn^{65}. In general, relative quantities of Zn^{65} in maize and barley plants followed the pattern, sheaths > roots > blades, in both harvests. However, in the first harvest, maize roots had higher concentration of Zn^{65} than did sheaths.

Autoradiography was used to get a picture of the overall distribution of zinc in the plants. Results are shown in figure 2. (The

(a) (b)

Fig. 2. Autoradiographs of intact (a) maize, and (b) barley plants supplied with 50 μg of Zn^{65} at 0 ppm level of zinc.

lighter stripes across some of the plant parts are due to absorption of beta radiation by cellophane tape). In the autoradiographs of maize plants Zn^{65} was fairly evenly distributed in the main and auxiliary roots with a relatively higher concentration in the root-stem junction. Zn^{65} was more concentrated in nodes than in internodes, probably due to the comparatively large amounts of vascular tissue in nodes. Also, sheaths and emerging young leaves showed higher concentrations than in older leaves. The distribution of Zn^{65} in barley was quite parallel to that for maize and patterns were also similar in runners and laterals.

Similar to the pattern in radioactive zinc, the total zinc content of roots, sheaths and blades of maize and barley plants increased significantly with increasing rate of zinc application. The distribution of total zinc, however, was different from that of radioactive zinc, in that total zinc content of roots was highest, followed by sheaths and blades.

TABLE 4

The effect of zinc application on the total zinc content and distribution in maize and barley plants

Zn rate ppm	Plant	Total zinc content (ppm)					
		Ist harvest			IInd harvest		
		Roots	Sheaths	Blades	Roots	Sheaths	Blades
0	Maize	60.8	24.0	16.3	32.5	11.4	8.8
0a		80.6	34.4	17.8	42.9	21.3	10.0
5a		91.9	44.5	28.5	53.1	21.8	18.6
25a		232.4	93.0	43.9	104.8	73.5	33.6
LSD		66.5	30.6	6.1	34.5	25.3	1.1
0	Barley	129.6	37.3	16.5	45.6	16.5	13.6
0a		136.8	47.4	18.5	55.7	14.9	19.7
5a		124.0	75.7	26.6	87.2	44.5	32.0
25a		216.2	136.0	67.4	114.9	110.9	62.1
LSD		–	30.0	23,2	–	23.6	3.2

a = activity of Zn^{65} (50μc/pot).

DISCUSSION

The observations on zinc deficiency showed that under identical experimental conditions maize plants showed zinc deficiency symptoms whereas barley plants did not. However, addition of zinc resulted in an increase of dry matter yield in barely plants. The larger growth of maize may have played a role in inducing zinc deficiency in maize plants. However, in general it has been found that plant species differ in requirements for zinc. For example, in species grown on a calcareous zinc-deficient soil, 7 developed zinc deficiency symptoms, 2 developed iron deficiency symptoms and 5 had no deficiency symptoms at all.[2] Gerloff[3] reported numerous examples that demonstrated marked differences in nutritional requirements of plant species and varieties.

The slight decrease in dry matter yield of barley plants at 25 ppm level of zinc compared with the 5 ppm level may possibly be due to antagonistic effects of zinc on the absorption of other micronutrients when the general level of micronutrients in soil is low. Gilbey *et al.*[4] reported that in regions with small amounts of Cu and Zn the rate of zinc application is critical, especially on coarse textured soils. If Zn is applied in greater amounts than recommended, zinc-induced copper deficiency is observed in barley and wheat.

In this study, an increased rate of zinc application resulted in greater uptake of both total and radioactive zinc by maize and barley plants. This effect has been reported by several investigators[8 12 14]. Navrot *et al.*[8], found that zinc fertilization of tomato plants in calcareous soil increased yield as well as Zn^{65} content and uptake. Yoshida[14] reported that zinc content of rice plant increased from 8 ppm in control pots to 151 ppm in treated pots (40 ppm Zn). Similar observations were reported in rice plants by Singh and Singh[12].

The distribution patterns of Zn^{65} drawn from the applied source and of total zinc were different. For Zn^{65}, content was highest in sheaths followed by roots and blades in both crops, whereas, for total zinc, content was highest in roots followed by sheaths and blades. Variable and contradictory results have been reported for other species. In seedlings of red oak, Brown and Taylor[1] found concentrations of Zn^{65} to rank: roots $>$ stem $>$ leaves. On the other hand Makhonina *et al.*[6], found Zn^{65} to be concentrated in

the above-ground portions of several plant species. Longaston [5] found that Zn^{65} accumulated to a marked degree in the stem, and in veins and petiols, of older leaves of tomato. This however, was the distribution for recently acquired zinc rather than for total zinc. This distribution of Zn^{65} in young tomato plants resembles the pattern found for maize and barley plants in the present study. The higher concentration of total zinc in roots suggests that a large fraction of the zinc absorbed by plants from the soil remained in the roots and was not translocated to the top parts of the plants.

Maize and barley plants developed very similar distribution patterns. In six-weeks-old plants, nodes and young leaves had higher concentration of Zn^{65} than internodes and older leaves, respectively. Riceman and Jones [9 10] found that in subterranean clover zinc is always present in high concentration in the terminal portions of the main axis, runners and lateral, young and expanding leaves, petioles and root tips. Turner and Gregory [13] also reported high concentration of zinc throughout the root systems as well as in the nodes and basal areas of the sheaths. The mature leaves had much lower concentrations than the expanding leaves. They attributed the higher concentration of zinc in nodes to the presence of vascular leaf tissues that terminate at the nodes. It is evident from this study that zinc concentration is higher in young parts and especially in veins, and is mobile through the sieve tubes in plants.

ACKNOWLEDGEMENTS

The authors appreciate the valuable suggestions contributed by Prof. Dr. J. Låg during the planning of this work. The assistance of Messrs. G. Østby and H. Lien and Mrs. R. Prestvik and financial support from NORAD are gratefully acknowledged.

Received August 19, 1973

REFERENCES

1 Brown, G. N. and Taylor, F. G., Zinc^{65} distribution and radiosensitivity of growth and Zn^{65} uptake in red oak seedlings. Radiation Botany **6**, 519–524 (1966).

2 Brown, J. C., Genetic variants as factor affecting the nutrient and physiology of the plants. Isotopes in plant nutrition and physiology. Proc. IAEA. Vienna, 413–420 (1967).

3 Gerloff, G. C., Comparative mineral nutrition of plants. Ann. Rev. Plant Physiol. **14**, 107–124 (1963).

4 Gilbey, D. J., Greathead, K. D., and Gartrell, J. W., Copper requirements for south eastern wheat belt. J. Agr. West. Australian **11**, 70–72 (1970).

5 Langston, R., Distribution patterns of radioisotopes in plants. Proc. Am. Soc. Hort. Sci. **68**, 370–376 (1956).

6 Makhonina, G. I., Molchanna, J. V., Subbotina, E. M., Timofeev-Resovskii N. V., Titlyanova, A. A., and Tyuryukanov, A. N., The experimental investigation of the distribution of radioisotopes in natural biogeocoenoses. Dokdady. Akad. Nauk, SSSR. **133**(2), 484–487 (1960).

7 Mitchell, R. L., Trace elements in soils. Chemistry of Soils, IInd Ed. pp. 320–368. Am. Chem. Soc. monograph series. Reinhold, NY (1964).

8 Navrot, J., Jacoby, B. and Ravikovitch, S., Fixation of Zn^{65} in some calcareous soils and its availability to tomato plants. Plant and Soil **27**, 141–147 (1967).

9 Riceman, D. S. and Jones, G. B., Distribution of zinc in subterranean clover (Trifolium subterranean L.) grown to maturity in a culture solution containing zinc labelled with the radioactive isotope Zn^{65}. Australian J. Agr. Research **9**, 730–744 (1958 c).

10 Riceman, D. S. and Jones, G. B., Distribution of recently absorbed zinc in subterranean clover (Trifolium subterranean L.) determined by adding radioactive zinc to the culture solution. Australian J. Agr. Research **11**, 887–891 (1960).

11 Shaw, E., Menzel, R. G., and Dean, L. A., Plant uptake of Zn^{65} from soils and fertilization in the green house. Soil Sci. **77**, 205–214 (1954).

12 Singh, B. R. and Singh, M., Studies on the supply of zinc to rice seedlings in Khaira affected lands. Indian J. Agr. Sci. (*submitted*) (1973).

13 Turner, R. G. and Gregory, R. P. G., The use of radioisotopes to investigate heavy metal tolerance in plants. Isotopes in plant nutrition and physiology. Proc. Sym. IAEA. Vienna 493–509 (1967).

14 Yoshida, S. and Tanaka, A., Zinc deficiency of the rice plants in calcarous soils. Soil Sci. and Plant Nutrition **15**, 75–80 (1969).