# Effect of Corn, Sugarbeets, and Fallow on Zinc Availability to Subsequent Crops

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# Effect of Corn, Sugarbeets, and Fallow on Zinc Availability to Subsequent Crops[1]

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## ABSTRACT

**Field observations indicated that Zn deficiency of beans (*Phaseolus vulgaris* L.) was sometimes more severe than expected when grown on fallowed soil that was low to marginal in available Zn. The objectives of this study were to determine the effects of fallow, sugarbeets (*Beta vulgaris* L.), and corn (*Zea mays* L.) on Zn availability to subsequent crops grown on a Portneuf silt loam (Durixerollic Calciorthids, coarse silty, mixed, mesic). The sugarbeet and corn plant tops and sugarbeet roots were removed, and 11.2 kg Zn ha$^{-1}$ was applied on one-half of each plot before fall plowing 25-cm deep. Beans, sweet corn, or potatoes (*Solanum tuberosum* L.) were planted the following spring. Whole plant samples of beans and sweet corn and potato stems, leaflets, and petioles were sampled for chemical analyses during the growing season. All bean plants were Zn deficient when grown after fallow or sugarbeets but not after corn or where Zn fertilized. Potatoes and sweet corn did not show any Zn deficiency symptoms or any growth responses to Zn fertilization. The average zinc concentration in beans (vegetative development stage, V3) following corn was 20.5 mg kg$^{-1}$ compared with 12.5 mg kg$^{-1}$ following fallow or sugarbeets without Zn fertilization. The average Zn uptake by beans (V3) following corn was 1.3 g ha$^{-1}$ compared with 0.6 g ha$^{-1}$ after fallow or sugarbeets without Zn fertilization. The Zn uptake after corn was even greater than where 11.2 kg Zn ha$^{-1}$ was applied to fallow or sugarbeets (1.3 vs. 0.9 g Zn ha$^{-1}$). Enhanced Zn availability following corn persisted throughout the growing season and into a second bean crop, although at a decreased level. Similar trends occurred with potatoes and sweet corn. Soil DTPA-extractable Zn was not significantly different after fallow, sugarbeets, or corn. These results indicate that Zn deficiency in sensitive crops may be alleviated or prevented depending upon the preceding crop grown, and that factors not measured by DTPA can significantly influence Zn availability.**

***Additional Index Words:*** **zinc deficiency, *Phaseolus vulgaris* L., *Solanum tuberosum* L., *Zea mays* L., nutrient recycling, root decomposition, chelation, DTPA-extractable Zn.**

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A PREVIOUS CROP of sugarbeets (*Beta vulgaris* L.) is recognized as a factor increasing the likelihood of Zn deficiency in subsequent crops. Zinc nutritional problems do not always arise following sugarbeets but they occur often enough to alert growers to the possibility. Boawn (1965) conducted a field experiment where sweet corn (*Zea mays* L.) was Zn deficient following sugarbeets but not following sugarbeets fertilized with Zn or sorghum (*Sorghum bicolor* L.). He concluded that sugarbeets had a deleterious effect on the Zn nutrition of subsequent crops. De Remer and Smith (1964) also mentioned the detrimental effect of sugarbeets on a subsequent crop of beans and indicated that returning beet tops to the soil aggravated the Zn deficiency problem. Boawn (1965) concluded that the presence of beet tops did not influence the results of his experiment.

Zinc deficiency of beans (*Phaseolus vulgaris* L.) is common in southern Idaho where control measures have been recommended for many years (Brown and LeBaron, 1968). Several situations were observed where beans were more severely Zn deficient than expected when grown on fallowed areas that were marginal to low in available Zn. These observations were not from controlled experiments and it was not known if, or how, fallow affected the disorder. Irrigated fields are seldom fallowed except where necessary for weed control or for other special problems. No literature citations were found that delineated the effects of fallow on the Zn nutrition of subsequent crops. The objective of this work was to determine the effect of fallow as compared to corn and sugarbeets on the Zn nutrition of subsequent crops.

## METHODS AND MATERIALS

Three field experiments were conducted on a Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthids) near Kimberly, ID during 1980 to 1983. The treatments in each experiment differed, but several management operations were common to all. A zinc sulfate solution (34.5 g Zn L$^{-1}$) was uniformly sprayed on the soil surface to give 11.2 kg Zn ha$^{-1}$ as the Zn treatment. Concentrated superphosphate (low Zn content) was broadcast according to the soil test (Olsen et al., 1954). Both materials were applied before moldboard plowing 25-cm deep. Nitrogen fertilizers were broadcast and worked into the surface 15 cm of the soil before seeding, except where side-dressed during the growing season.

Irrigation water was applied in furrows according to tensiometers placed 45-cm deep in one crop row in each replication. The fallowed plots were irrigated at the same time and for the same duration as were the corn and sugarbeet plots during the differential cropping. At the end of the differential cropping season the corn was harvested for silage. The sugarbeets were machine harvested and removed from the plot areas along with their tops. Cropping treatments for the three experiments are summarized in Table 1.

### Experiment I

The experimental area was uniformly cropped with dry peas (*Pisum sativa* L.) in 1978. Fallow and field corn plots, 9.1 by 27.4 m, were established in 1979 in a randomized block design with four replications. Corn ('Pioneer 3901') was planted in 70-cm rows with the seeds spaced 15 cm apart. The corn was fertilized with 155 kg N ha$^{-1}$ as $NH_4NO_3$ before planting.

After harvest the corn and fallow plots were randomly split and one-half received Zn fertilizer. The entire experiment received 45 kg N ha$^{-1}$ as $NH_4NO_3$ the spring of 1980 before planting six bean cultivars (Table 2) on May 28. The cultivars were planted in four-row plots with the seeds spaced 7 cm apart in 56-cm rows. The experimental design was a split-split plot with four replications.

### Experiment II

A second experiment was established in 1981 on land adjacent to Exp. I that had been uniformly cropped with spring wheat (*Triticum aestivum* L.) in 1980. All the wheat stubble

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**Table 1. Cropping sequence and Zn treatments for Exp. I, II, and III.**

| Experiment no. | Last uniform crop | Treatments: Crops | Treatments: Zn† | Test crops |
|---|---|---|---|---|
| I | Dry peas (1978) | Fallow, corn (1979) | +, − | Beans (1980) |
| II | Spring wheat (1980) | Fallow, sugarbeets, corn (1981) | +, − | Beans, potatoes (1982) beans (1983) |
| III | Beans (1981) | Fallow, corn (1982) | +, − | Sweet corn (1983) |

† +, − = 11.2 kg Zn ha$^{-1}$ or no Zn applied before test crop, respectively.

**Table 2. The growth, Zn concentration, and uptake by six bean cultivars grown following corn or fallow as affected by Zn fertilization (whole plants sampled July 10, V3 developmental growth stage, Exp. I).**

| Zn applied | Variety | Dry weight | Zn conc. | Zn uptake |
|---|---|---|---|---|
| kg ha$^{-1}$ | | kg ha$^{-1}$ | mg kg$^{-1}$ | g ha$^{-1}$ |
| | | | Fallow | |
| 0 | Early Galatin | 41 | 12.2 | 0.50 |
| | BBL GV #2 | 39 | 10.0 | 0.39 |
| | Red Mex. | 47 | 11.7 | 0.55 |
| | Pinto | 44 | 9.5 | 0.42 |
| | Viva | 31 | 11.2 | 0.35 |
| | Sanilac | 19 | 8.7 | 0.16 |
| | Avg | 37 | 10.5 | 0.39 |
| | | | Corn | |
| 0 | Early Galatin | 82 | 18.2 | 1.49 |
| | BBL GV #2 | 81 | 18.2 | 1.47 |
| | Red Mex. | 109 | 18.7 | 2.04 |
| | Pinto | 71 | 18.2 | 1.29 |
| | Viva | 65 | 20.2 | 1.31 |
| | Sanilac | 45 | 15.2 | 0.68 |
| | Avg | 75 | 18.1 | 1.38 |
| | | | Fallow | |
| 11.2 | Early Galatin | 72 | 19.5 | 1.40 |
| | BBL GV #2 | 65 | 17.2 | 1.12 |
| | Red Mex. | 88 | 19.7 | 1.73 |
| | Pinto | 63 | 16.2 | 1.02 |
| | Viva | 60 | 22.7 | 1.36 |
| | Sanilac | 40 | 12.7 | 0.51 |
| | Avg | 64 | 18.0 | 1.19 |
| | | | Corn | |
| 11.2 | Early Galatin | 96 | 27.2 | 2.61 |
| | BBL GV #2 | 90 | 26.0 | 2.34 |
| | Red Mex. | 105 | 26.2 | 2.75 |
| | Pinto | 70 | 25.7 | 1.80 |
| | Viva | 63 | 28.5 | 1.80 |
| | Sanilac | 50 | 21.0 | 1.05 |
| | Avg | 79 | 25.7 | 2.06 |
| Previous crop | | ** | ** | ** |
| LSD 0.05 | | 10 | 2.0 | 0.34 |
| Zn fertilization | | ** | ** | ** |
| LSD 0.05 | | 4.0 | 2.0 | 0.26 |
| Variety | | ** | ** | ** |
| LSD 0.05 | | 10 | 1.9 | 0.26 |

was fall incorporated into the soil by moldboard plowing 25-cm deep. Precropping treatments included fallow, corn, and sugarbeets in plots that were 9.1 by 27.4 m. Both the corn and sugarbeets were planted in 61-cm rows to facilitate cultivation and irrigation. The sugarbeets were thinned to a within row spacing of 25 cm. Corn and sugarbeets were fertilized with 155 kg N ha$^{-1}$ as urea. After harvest, 67 kg P ha$^{-1}$ was applied to all plots and Zn was applied to one-half of each plot.

In the spring of 1982, 45 kg N ha$^{-1}$ as $NH_4NO_3$ was uniformly applied before planting. Russet Burbank potato (*Solanum tuberosum*) seed pieces were planted May 8 in four-row plots with seed spaced 15 cm apart in 76-cm rows. Ammonium nitrate (212 kg N ha$^{-1}$) was side-dressed on the potatoes May 28. Two bean cultivars, Sanilac and Viva, were planted about June 1 in 61-cm rows. Because the bean cultivars and the potatoes were not randomized in the field, the data from each were statistically analyzed separately as a split plot design with four replications. The 2nd yr (1983) after the differential cropping, Viva beans were planted June 10 on all plots to determine residual effects of the precropping treatments without any additional fertilizer.

## Experiment III

A third experiment was established in 1982 having fallow and corn as the precropping treatments in plots that were 9.1 by 27.4 m. Beans had been grown uniformly over the area in 1981. The corn was fertilized with 155 kg N ha$^{-1}$ as urea. After harvesting the corn for silage, all plots were fertilized with 45 kg P ha$^{-1}$ and one-half of each plot received Zn fertilizer. In 1983, 155 kg N ha$^{-1}$ as urea was uniformly applied and worked into the soil before planting Golden Cross Bantam and Code 48 sweet corn cultivars on June 10. Because of variability in stand and growth only two replications of this experiment were utilized in the statistical analysis.

## Soil and Plant Samples

Soil samples consisting of 15 cores, 30 by 2.5 cm, were taken from each plot in the spring of each year. The samples were spread on plastic-covered metal trays, dried at 33°C in a forced draft drying cabinet, and crushed in a stainless steel flail-type crusher to pass a 2-mm sieve. All samples were analyzed for $NaHCO_3$-soluble P and K (Olsen et al., 1954) and DTPA-extractable Zn, Fe, Mn, and Cu (Lindsay and Norvell, 1978). Selected samples were analyzed for $NO_3^-$-N (Milham et al., 1970) to aid in determining N fertilizer requirements.

Whole bean plant samples were obtained by pulling plants at random from areas having near perfect stands. Each plot was sampled three times in Exp. I and five times in Exp. II. The number of plants taken in each sample varied from 20, when the plants were small, and to 10 as they approached maturity. The average plant development growth stage was estimated at each sampling according to LeBaron (1974). The roots were clipped from the plants while still fresh. The plant samples were washed in distilled water, dried in forced draft ovens at 65°C, and ground to pass a 1-mm sieve in a Wiley mill equipped with stainless steel parts.

Potato tissue samples consisted of 10 randomly selected stems taken 52 d after planting, stripped of petioles and leaflets, and dried and ground in the same manner as the bean plants. In addition, 50 fourth-petioles from the growing end of the stem, with leaflets, were randomly selected from each plot. The leaflets were stripped from the petioles and the two types of tissue samples were treated the same as the stem samples.

Sweet corn samples were obtained by randomly selecting 10 whole plants from each plot on July 28, 48 d after planting. The roots were removed and the samples washed in distilled water. They were cut into small pieces, dried, and ground the same as the bean and potato samples.

Weighed dry samples of plant material were digested in a mixture of nitric and perchloric acids (3:1), filtered and the solutions analyzed for P colorimetrically (Kitson and Mellon, 1944), and Zn, Cu, Mn, Fe, K, Ca, and Mg using atomic absorption techniques. Total N (Bremner, 1965), B (Wolf, 1974), and S (Tabatabai and Bremner, 1970) were determined on selected samples.

**Table 3. The growth, Zn concentration, and Zn uptake of Sanilac and Viva beans sampled during the growing season as affected by previous crop and Zn fertilization (Exp. II).**

| | | Sampling date† | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sanilac | | | | | Viva | | | | |
| Prev. crop | Zn applied | 6/17 | 7/1 | 7/12 | 7/27 | 8/17 | 6/17 | 7/1 | 7/12 | 7/27 | 8/17 |
| | kg ha$^{-1}$ | Dry weight, kg ha$^{-1}$ | | | | | | | | | |
| Fallow | 0 | 7 | 26 | 61 | 261 | 878 | 7 | 45 | 133 | 528 | 1490 |
| | 11.2 | 7 | 45 | 125 | 403 | 1190 | 7 | 53 | 156 | 627 | 1520 |
| Sugarbeets | 0 | 7 | 34 | 106 | 380 | 1060 | 7 | 49 | 152 | 574 | 1480 |
| | 11.2 | 7 | 49 | 144 | 555 | 1300 | 7 | 57 | 205 | 672 | 1660 |
| Corn | 0 | 7 | 57 | 163 | 616 | 1270 | 7 | 61 | 190 | 672 | 1680 |
| | 11.2 | 7 | 57 | 194 | 593 | 1340 | 7 | 64 | 209 | 733 | 1570 |
| Previous crop | | NS | ** | ** | * | * | NS | NS | * | ** | NS |
| LSD 0.05 | | – | 7 | 38 | 148 | 197 | – | – | 26 | 45 | – |
| Zn fertilized | | NS | ** | ** | ** | ** | NS | * | * | ** | NS |
| LSD 0.05 | | – | 11 | 19 | 49 | 125 | – | 4 | 23 | 57 | – |
| | | Zn concentration, mg kg$^{-1}$ | | | | | | | | | |
| Fallow | 0 | 9.7 | 12.5 | 13.0 | 13.0 | 11.7 | 14.2 | 15.5 | 18.2 | 17.2 | 13.7 |
| | 11.2 | 11.5 | 14.2 | 13.2 | 12.7 | 11.2 | 16.0 | 19.0 | 21.7 | 18.5 | 14.0 |
| Sugarbeets | 0 | 10.0 | 14.7 | 15.0 | 14.2 | 12.7 | 14.7 | 17.7 | 22.7 | 19.6 | 15.6 |
| | 11.2 | 11.0 | 16.7 | 16.2 | 14.7 | 12.5 | 15.0 | 22.0 | 24.2 | 21.5 | 15.7 |
| Corn | 0 | 11.0 | 20.2 | 20.7 | 16.5 | 12.2 | 17.5 | 25.7 | 29.2 | 22.0 | 15.2 |
| | 11.2 | 13.0 | 24.7 | 22.7 | 17.5 | 12.7 | 18.0 | 29.7 | 34.2 | 26.5 | 17.2 |
| Previous crop | | NS | ** | ** | ** | NS | * | ** | ** | ** | * |
| LSD 0.05 | | – | 2.5 | 2.1 | 0.5 | – | 1.1 | 2.9 | 2.0 | 2.0 | 1.4 |
| Zn fertilized | | * | * | * | NS | NS | NS | ** | ** | ** | * |
| LSD 0.05 | | 0.7 | 1.3 | 1.1 | – | – | – | 1.2 | 2.0 | 1.1 | 0.5 |
| | | Zn uptake, g ha$^{-1}$ | | | | | | | | | |
| Fallow | 0 | 0.07 | 0.34 | 0.83 | 3.29 | 10.3 | 0.11 | 0.68 | 2.43 | 9.1 | 20.5 |
| | 11.2 | 0.07 | 0.64 | 1.67 | 5.09 | 13.3 | 0.11 | 0.99 | 3.38 | 11.5 | 21.3 |
| Sugarbeets | 0 | 0.07 | 0.53 | 1.59 | 5.39 | 13.5 | 0.11 | 0.87 | 3.46 | 11.2 | 23.1 |
| | 11.2 | 0.07 | 0.87 | 2.32 | 8.13 | 16.2 | 0.11 | 1.25 | 5.01 | 14.4 | 26.1 |
| Corn | 0 | 0.07 | 1.10 | 3.38 | 10.1 | 15.5 | 0.11 | 1.56 | 5.55 | 14.8 | 25.5 |
| | 11.2 | 0.11 | 1.44 | 4.37 | 10.4 | 17.0 | 0.15 | 1.90 | 7.14 | 19.4 | 27.0 |
| Previous crop | | NS | ** | ** | ** | * | NS | ** | ** | ** | * |
| LSD 0.05 | | – | 0.19 | 0.57 | 2.35 | 3.00 | – | 0.38 | 0.80 | 2.20 | 3.42 |
| Zn fertilized | | NS | ** | ** | ** | ** | NS | * | ** | ** | NS |
| LSD 0.05 | | – | 0.07 | 0.38 | 0.64 | 1.59 | – | 0.15 | 0.72 | 1.02 | – |

† 6/17, 7/1, 7/12, 7/27, 8/17 = V2, V3, V4, V6, R3 developmental growth stages, respectively.

## RESULTS

### Experiment I

All six bean cultivars fertilized with Zn grew normally. Without Zn fertilizer those plants grown after fallow developed severe Zn deficiency symptoms about July 1; following corn, however, the plants showed only slight symptoms. The affected plants began to grow out of the Zn deficiency about July 25. This recovery pattern is normal for Zn deficient beans in this area. The main effect of the deficiency is a delay in maturity, the length of which depends on the severity of the Zn deficiency. If the season is not ended by frost, maturity may be delayed as much as 30 d (Boawn et al., 1969).

The growth, Zn concentration, and Zn uptake for the six cultivars on July 10 parallel the visual evaluations made at sampling time (Table 2). The average dry weight of the plants following corn without Zn fertilizer was twice that for plants grown after fallow without Zn fertilizer and slightly larger than those grown on fallow fertilized with Zn.

The average Zn concentration in the whole plants grown without Zn fertilization was 10.5 and 18.1 mg kg$^{-1}$ following fallow and corn, respectively (Table 2). Where Zn was applied, the average plant Zn concentration was 18.0 mg kg$^{-1}$ for those grown after fallow and 25.7 mg kg$^{-1}$ for those following corn. The average Zn uptake by plants grown after corn was 1.7 and 3.5 times that by plants following fallow with and without Zn fertilization, respectively. Corn, as a preceding crop, had more effect on Zn uptake by the bean plants than 11.2 kg Zn ha$^{-1}$ applied to fallow.

### Experiment II

Sanilac and Viva beans grown after fallow or sugarbeets without Zn fertilizer developed well-defined visual Zn deficiency symptoms. Those grown after corn showed only slight Zn deficiency symptoms. Generally, the symptoms were not as severe as those for the same cultivars in Exp. I.

Plant growth of Sanilac without Zn fertilization was larger following corn than following sugarbeets or fallow (Table 3). A similar comparison for Viva indicates the same trend. Plant size for both cultivars was unaffected by differential cropping when Zn fertilized.

The Zn concentration in whole bean plants grown after corn was generally greater than that of those grown after sugarbeets or fallow at both Zn rates (Table 3). The higher Zn concentration in plants grown after corn as compared to those grown after fallow or sugarbeets is emphasized in Fig. 1. The Zn concen-

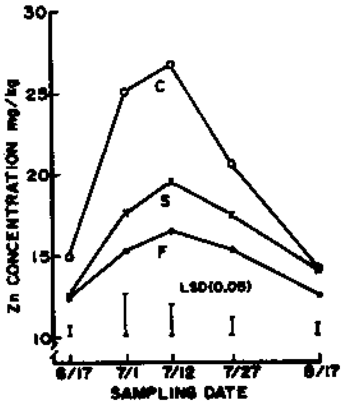


**Fig. 1. The Zn concentration of beans grown after fallow (F), sugarbeets (S), and corn (C). Data are averages of Sanilac and Viva beans grown at 0 and 11.2 kg Zn ha$^{-1}$.**

**Table 4. The Zn concentrations in potato tissues sampled June 29 as influenced by previous crop and Zn fertilization (Exp. II).**

| Previous crop | Zn applied | Plant Zn: Stems | Petioles | Leaflets |
|---|---|---|---|---|
| | kg ha$^{-1}$ | mg kg$^{-1}$ | | |
| Fallow | 0 | 14.2 | 19.7 | 23.0 |
| | 11.2 | 21.7 | 24.2 | 26.2 |
| Sugarbeets | 0 | 16.2 | 21.7 | 24.0 |
| | 11.2 | 29.2 | 27.5 | 28.2 |
| Corn | 0 | 21.0 | 24.2 | 25.7 |
| | 11.2 | 37.5 | 29.2 | 28.5 |
| Previous crop | | ** | ** | NS |
| LSD 0.05 | | 5.1 | 1.4 | – |
| Zn fertilization | | ** | ** | ** |
| LSD 0.05 | | 2.4 | 1.9 | 1.5 |

tration in the plants following sugarbeets was intermediate between that of those grown after fallow and corn, but closely paralleled those grown on fallow. Generally, the Zn concentration of the fertilized plants was higher than those unfertilized throughout most of the growing season, but was about the same as the bean plants approached maturity in mid-August.

The Zn uptake by Sanilac was 10.1, 5.4, and 3.3 g Zn ha$^{-1}$ on July 27 for the corn, sugarbeets, and fallow treatments without Zn fertilization, respectively (Table 3). A similar comparison showed that the Zn uptake was 10.4, 8.1, and 5.1 g Zn ha$^{-1}$ for the same treatments where Zn was applied. The Zn uptake following corn was similar for both Zn rates, whereas the Zn uptake following beets or fallow was greater where Zn fertilizer was applied. The Zn uptake following corn without Zn fertilizer was equal to or greater than that measured following fallow or sugarbeets either with or without Zn fertilizer. The larger Zn uptake following corn was not only from larger plants but also from an increased Zn concentration in the plants.

The potato plants did not show Zn deficiency symptoms (Boawn and Leggett, 1963) on any plots in Exp. II. The Zn concentrations in the stem and petiole tissues were affected by the cropping sequence in the same way as the beans (Table 4). The average Zn concentration in the potato stems was 59 and 77% after fallow and sugarbeets, respectively, of that following corn. The Zn concentration differences between treatments were smaller in the potato leaflets than in the stems or petioles and only significant ($P = 0.01$) for Zn fertilization.

The effects of the differential cropping were still evident in the 2nd yr in Viva beans, but were diminished from those measured a year earlier in the first bean test crop (Table 3 vs. Table 5). For example, the Zn concentration in the plants sampled July 29 avg 18.8, 22.5, and 25.0 mg kg$^{-1}$ for those grown on the fallow, sugarbeets, and corn plots, respectively. The average Zn uptake after fallow and sugarbeets was 63 and 82% of that following corn, respectively. The residual effect of the differential cropping was also evident with and without Zn fertilization.

## Experiment III

Neither sweet corn cultivar showed Zn deficiency symptoms, although the Zn fertilized plants appeared slightly larger than those where no Zn was applied. The Zn concentration and Zn uptake (Table 6) paralleled the data given for beans and potatoes. The average Zn concentration of the whole plants without Zn fertilization increased from 12.7 after fallow to 18.7 mg kg$^{-1}$ after corn. Moreover, the unfertilized sweet corn plants following corn had higher Zn concentrations than those grown on fallow fertilized with Zn. Zinc uptake by the two cultivars following corn also was larger than those following fallow, but the differ-

**Table 5. The growth, Zn concentration and Zn uptake of Viva beans grown 2 yr after differential cropping (Exp. II, 2nd yr).**

| Initial crop | Zn applied | Sampling date†: 7/12 | 7/22 | 7/29 | 8/11 | 7/12 | 7/22 | 7/29 | 8/11 | 7/12 | 7/22 | 7/29 | 8/11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | Dry weight, kg ha$^{-1}$ | | | | Zn concentration, mg kg$^{-1}$ | | | | Zn uptake, g ha$^{-1}$ | | | |
| Fallow | 0 | 23 | 65 | 144 | 384 | 16.0 | 17.2 | 17.7 | 16.2 | 0.3 | 1.1 | 2.5 | 6.2 |
| | 11.2 | 29 | 87 | 163 | 422 | 19.2 | 20.0 | 20.0 | 18.5 | 0.6 | 1.7 | 3.3 | 7.8 |
| Sugarbeets | 0 | 27 | 80 | 159 | 395 | 18.2 | 21.2 | 21.5 | 21.5 | 0.5 | 1.7 | 3.4 | 8.5 |
| | 11.2 | 29 | 84 | 175 | 456 | 21.5 | 22.7 | 23.5 | 21.8 | 0.6 | 1.9 | 4.1 | 9.9 |
| Corn | 0 | 27 | 80 | 190 | 433 | 19.2 | 22.2 | 23.2 | 20.0 | 0.5 | 1.8 | 4.4 | 8.7 |
| | 11.2 | 30 | 91 | 178 | 467 | 23.5 | 26.2 | 26.7 | 24.5 | 0.7 | 2.4 | 4.8 | 11.4 |
| Previous crop | | NS | ** | * | NS | * | * | ** | NS | NS | * | ** | ** |
| LSD 0.05 | | – | 8 | 2 | – | 2.8 | 3.2 | 2.3 | – | – | 0.4 | 0.9 | 1.6 |
| Zn fertilization | | ** | ** | NS | NS | ** | ** | ** | ** | ** | ** | * | ** |
| LSD 0.05 | | 2 | 15 | – | – | 1.1 | 1.7 | 0.6 | 1.1 | 0.1 | 0.2 | 0.6 | 1.6 |

† 7/12, 7/22, 7/29, 8/1 = V2, V3, V6, R1 developmental growth stages, respectively.

ences were only significant at $P = 0.10$ and 0.25 for the Golden Cross Bantam and Code 48 cultivars, respectively.

The DTPA-extractable soil Zn for treatments in Exp. II (Table 7) indicate that the experimental area was initially uniformly low in available Zn and the differential cropping did not affect the extractable Zn of the unfertilized plots measurably (November 1981 and May 1982 and 1983). The Zn soil tests were increased an avg of 1.0 mg $kg^{-1}$ 180 d after applying Zn (May 82) and 0.7 mg $kg^{-1}$ 1 yr later. Similar results (data not presented) were obtained for Exp. I and III.

Although not reported here, Cu concentration and uptake by all six bean cultivars were affected the same as Zn, in Exp. I. The same trend also occurred with Sanilac beans but not with Viva beans or potatoes in Exp. II, or with either sweet corn cultivar grown in Exp. III. Phosphorus, K, Ca, Mg, Fe, N, B, S, and Mn data are not presented but the concentrations of these elements were generally lower where growth was increased from increased Zn availability. The uptake of these elements generally increased because of the offsetting effect of larger plants rather than the combined effects of increased concentration and plant size shown for Zn.

## DISCUSSION

The data presented here clearly indicate a beneficial effect of corn over fallow or sugarbeets as the preceding crop in increasing the availability of Zn to beans, potatoes, and sweet corn. For beans the benefit was evident in increased growth, Zn concentration of the whole plants, and Zn uptake for all cultivars tested, some of which were more sensitive to Zn deficiency than others. Potato and sweet corn growth were not visually influenced by previous cropping or Zn fertilization; nevertheless, both treatments affected the Zn concentration of tissues in both species. A striking aspect of these data was the magnitude of the previous crop effect on Zn concentration, even where Zn was abundant.

With the data at hand we are unable to determine the factors that increased Zn availability to crops following corn. Hypotheses that appear attractive are (i) recycling of elements through roots, (ii) chelate formation during corn root growth or decomposition (Stevenson and Ardakani, 1978), (iii) unknown or unrecognized deleterious effects from growing sugarbeets (Boawn, 1965) or from fallow, (iv) stimulatory substances given off from growing or decomposing roots, and (v) mycorrhizal effects (Vesicular-arbuscular mycorrhiza) (Lambert et al., 1979). Each of these hypotheses is not necessarily considered to be the sole factor responsible for enhanced Zn uptake following corn. Combinations of these hypotheses, and others not listed, may be required. For example, recycling Zn through plant roots and chelate formation during root decomposition is a logical combination.

The recycling of Zn through roots does not appear to be the dominant factor in enhancing Zn availability by a previous corn crop. About four times more corn roots than sugarbeet roots were obtained from a given volume of soil after harvest. The beet roots contained 88 mg Zn $kg^{-1}$ whereas the corn roots contained 27 mg Zn $kg^{-1}$. These data indicate only a small difference in total Zn available for recycling in favor of corn over sugarbeets. In addition, other elements also subject to recycling were not always affected in the same way as was Zn. For example, the Cu concentration of sugarbeet roots was also about four times that of corn roots, yet a previous corn crop did not always enhance the Cu concentration of subsequent crops.

The chelate hypothesis is attractive but it does not explain why Zn was the only element consistently affected by differential cropping. Lindsay (1974) summarized data showing that synthetic chelates are distributed among several elements in the soil solution according to stability constants, concentration of chelate, solubility of the elements, and pH. Presumably, the availability of the chelated nutrients would be affected in relation to their concentrations in the soil solution; however, this concept is not supported by all experimental data (Wallace and Romney, 1970). Thus, any chelate formed during root decomposition should affect the concentrations of several nutrients in the plants similar to that of Zn. The results reported here indicate that Zn was the only element consistently affected by the differential cropping even after almost 2 yr equilibration time after the initial cropping treatments. If chelation was responsible for the effects noted in these experiments, the chelate(s) formed would have to have a high specificity for Zn.

The hypothesis related to vesicular-arbuscular mycorrhizae is reasonable. No attempt was made to assay the corn or sugarbeet roots for the presence of these fungi. A preliminary assay of the bean roots in Exp. II showed that the roots from both fertilized and unfertilized plots had some spores and hyphae present

**Table 6. The dry weight, Zn concentration, and Zn uptake of two sweet corn cultivars (5–6 leaves) as influenced by previous crop and Zn fertilization (Exp. III).**

| Previous crop | Zn applied | Dry weight GCB† | Dry weight Code 48 | Zn conc. GCB | Zn conc. Code 48 | Zn uptake GCB | Zn uptake Code 48 |
|---|---|---|---|---|---|---|---|
| | | kg $ha^{-1}$ | | mg $kg^{-1}$ | | g $ha^{-1}$ | |
| Fallow | 0 | 76 | 83 | 14.5 | 11.0 | 1.1 | 0.9 |
| | 11.2 | 111 | 112 | 15.5 | 14.0 | 1.7 | 1.6 |
| Corn | 0 | 131 | 107 | 19.5 | 18.0 | 2.5 | 1.9 |
| | 11.2 | 117 | 103 | 22.0 | 20.5 | 2.6 | 2.1 |
| LSD 0.05 | | – | – | 3.3 | 3.8 | – | – |

† GCB = golden cross bantam.

**Table 7. Means ± $t_{0.05}$ $s_{\bar{x}}$ for DTPA extractable Zn for treatments in Exp. II.**

| Prev. crop | Zn applied† | DTPA-extractable Zn Nov. 81 | May 82 | May 83 |
|---|---|---|---|---|
| | kg $ha^{-1}$ | mg $kg^{-1}$ | | |
| Fallow | 0 | 0.42 ± 0.07 | 0.52 ± 0.13 | 0.55 ± 0.08 |
| | 11.2 | 0.42 ± 0.07 | 1.67 ± 0.30 | 1.27 ± 0.45 |
| Sugarbeets | 0 | 0.52 ± 0.07 | 0.60 ± 0.13 | 0.60 ± 0.11 |
| | 11.2 | 0.52 ± 0.07 | 1.27 ± 0.15 | 1.22 ± 0.30 |
| Corn | 0 | 0.42 ± 0.07 | 0.50 ± 0.08 | 0.50 ± 0.03 |
| | 11.2 | 0.42 ± 0.07 | 1.40 ± 0.33 | 1.07 ± 0.17 |

† Zinc fertilizer applied December 1981 before plowing.

but few infection sites. There were no apparent differences related to previous crop.

The effect of sugarbeets on Zn nutrition of a subsequent corn crop has been interpreted as a deleterious effect (Boawn, 1965). Zinc uptake was low at both Zn fertilizer rates following sugarbeets and fallow compared to following corn. These data indicate that instead of sugarbeets and fallow adversely affecting subsequent crops, corn may be enhancing the Zn nutrition of subsequent crops. This concept is supported by the larger Zn concentrations in potatoes, sweet corn, and beans grown after corn than following sugarbeets or fallow, and that this enhancement occurred even where Zn fertilizer was applied, as well as where plant growth increased.

The residual effect of precropping reported here differs from Boawn's results where sorghum and sugarbeets were the previous crops. His first test crop, sweet corn, showed a strong effect of previous crop on Zn nutrition (Boawn, 1965), whereas beans grown the 2nd yr did not (Boawn, 1985, personal communication). He concluded that the effect lasted only 1 yr. In view of the results presented here, the positive effect of corn grown over Boawn's entire experiment the 1st yr after differential cropping would be expected to overcome any residual effect remaining for the following bean crop. Thus, our results following sugarbeets are similar to Boawn's, and the effects of fallow and sugarbeets on the Zn nutrition of subsequent crops are considered to be similar if not the same.

Attempts to reproduce the preceding crop effect on Zn availability under growth chamber or greenhouse conditions were unsuccessful. Beans were grown in various size pots on soil that showed very strong preceding-crop effects under field conditions. Severely Zn deficient beans were grown but plant growth and chemical compositions were not affected by the previous cropping practice. Other greenhouse and growth chamber experiments contained differential cropping treatments, i.e., soil was fallowed or cropped to corn or beans before planting the test crop of beans; however, no prior crop effects on growth or Zn uptake were observed.

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