Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

RESEARCH AND DEVELOPMENT DEPARTMENT

REPORT NO. 04-23

DETERMINATION OF PHYTOTOXIC ZINC THRESHOLDS IN LEAVES OF GRASSES AND FOOD AND FIBER CROPS

December 2004

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DETERMINATION OF PHYTOTOXIC ZINC THRESHOLDS IN LEAVES OF GRASSES AND FOOD AND FIBER CROPS

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December 2004

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ACKNOWLEDGEMENT

The authors would like to thank Tricia Stefanich, Laboratory Technician III, Robert Hermann, Laboratory Technician II (retired), Rebecca Rose, Laboratory Technician III, and Thota Reddy, Laboratory Technician II for their assistance in conducting the study.

The authors would also like to thank John Gschwind, Sanitary Chemist IV (retired), Tom Liston, Sanitary Chemist IV, and Ron Rivers, Sanitary Chemist I of the Calumet Analytical Laboratory for their careful analysis of all the soil and plant tissue samples.

Finally, the authors would like to express appreciation to Dr. Cecil Lue-Hing, Dr. Prakasam Tata, and Dr. Richard Pietz for their support and encouragement during the conduct of the study; Mr. Bernard Sawyer for his thoughtful review of the report; and Ms. Nancy Urlacher for her assistance in preparing the final report.

DISCLAIMER

Mention of proprietary equipment and chemicals in this report does not constitute endorsement by the Metropolitan Water Reclamation District of Greater Chicago.

SUMMARY AND CONCLUSIONS

This study utilized soils spiked with soluble zinc (Zn) salts to assess the relationship of plant leaf Zn concentration and plant growth. The point at which the leaf Zn concentration first results in a reduction in plant growth is referred to as the phytotoxic Zn threshold. Phytotoxic Zn thresholds were determined for 15 plant species in this study by growing the plants in the spiked soils in large pots for four to ten weeks in a research greenhouse maintained by the Metropolitan Water Reclamation District of Greater Chicago (District).

Two beet varieties were sampled and analyzed at 4 weeks and again at 10 weeks (maturity). In both cases the phytotoxic Zn threshold determined at 4 weeks was lower than the threshold determined at 10 weeks indicating that the plants are more sensitive to Zn phytotoxicity at earlier stages of their life cycle. We therefore conclude that these studies, which were conducted on plants not grown to maturity, are conservative.

Three varieties of beet and two varieties of lettuce were included in the study. The phytotoxic Zn threshold was found to vary among varieties or cultivars of the same species. A single phytotoxic threshold therefore cannot accurately represent all varieties or cultivars of a species.

The results of the study were utilized to evaluate the phytotoxic Zn threshold utilized in the Part 503 risk assessment, 400 mg Zn kg^{-1} leaf tissue. Four species had phytotoxic Zn thresholds above 1,000 mg Zn kg^{-1} leaf tissue including beet (v. Early Wonder), reed canary grass, perennial ryegrass, and tall fescue. Five species had phytotoxic Zn thresholds above 600 mg Zn kg^{-1} leaf tissue, including beet (v. Ruby Queen), spinach, Kentucky bluegrass, buffalo grass, and oat. Six species had phytotoxic Zn thresholds above 400 mg Zn kg^{-1} leaf tissue, including beet (v. Red Ball), cotton, corn, red top, tomato, and wheat. The Part 503 risk assessment is very conservative and protective for these species.

The Part 503 risk assessment identified lettuce as the most sensitive species and utilized it to set the phytotoxic Zn threshold. This study corroborates this since lettuce had the lowest measured phytotoxic Zn threshold. In this study two varieties of lettuce and creeping bentgrass were found to have estimated phytotoxic Zn thresholds below the Part 503 threshold of 400 mg Zn kg^{-1} leaf tissue. Iceberg lettuce was determined to have a phytotoxic Zn threshold of 380 mg Zn kg^{-1} leaf tissue with 413 mg Zn kg^{-1} leaf tissue estimated to cause 25 percent growth reduction (this is very similar to the Part 503 lettuce based threshold). Creeping bentgrass had an estimated phytotoxic Zn threshold of 300 mg Zn kg^{-1} leaf tissue, and it was estimated that 543 mg Zn kg^{-1} leaf tissue would be required for a 25 percent growth reduction. Therefore, applying the Part 503 threshold to this species would not result in a growth reduction of greater than 25 percent. Black Seeded Simpson lettuce was the most sensitive species tested. In the two trials in which it was grown it had estimated Zn phytotoxic thresholds of 130 and 230 mg Zn kg^{-1} leaf tissue. In both cases applying the Part 503 threshold to this species would result in a growth reduction of 25 to 50 percent but likely closer to 25 percent. Use of the Part 503 phytotoxic Zn threshold of 400 mg Zn kg^{-1} leaf tissue is protective of nearly all species tested and may result in a growth reduction of only approximately 25 percent for the most sensitive species.

Turfgrass was variable in its sensitivity to Zn. Creeping bentgrass showed the most sensitivity while tall fescue was the most tolerant. A set of diagnostic leaf tissue concentrations were developed that can be used to identify Zn phytotoxicity where questions arise at biosolids project sites. Zinc concentrations in leaves of turf grasses grown in District biosolids have never been observed to be as high as these thresholds.

INTRODUCTION

In 1993 the United States Environmental Protection Agency promulgated their 40 CFR Part 503 "Standards for the Use or Disposal of Sewage Sludge". The Part 503 regulation is risk based and utilizes 14 exposure pathways to set regulatory limits for 9 trace elements for land applied biosolids. The Part 503 limits for Cu, Ni, and Zn were set to be protective of phytotoxicity since the biosolids → soil → plant (phytotoxicity) pathway produced the most restrictive regulatory limits for these elements (USEPA, 2002). During the development of the risk analysis for the Part 503 phytotoxicity pathway Chang et al. (1992) proposed an approach that involved using published information in the scientific literature in which plants were exposed to elevated concentrations of only one of the trace elements (either Cu, Ni, or Zn) at a time to establish a relationship between leaf trace element concentration and plant growth reduction. The approach called for establishing phytotoxic threshold leaf trace element concentrations which correspond to a 50 percent growth reduction in four to eight week old seedlings. The phytotoxic thresholds would then be used in conjunction with plant uptake coefficients, which relate trace element loading to soil from biosolids to plant tissue trace element concentration, to determine the phytotoxic biosolids loading threshold.

The USEPA subsequently utilized a somewhat different approach to derive the regulatory limit for Zn from the phytotoxicity pathway. The USEPA utilized the lowest observed adverse effect level to set the phytotoxic threshold leaf Zn concentration (USEPA, 2002). This turned out to be 400 $\mu g\ Zn\ g^{-1}$ plant tissue based on studies conducted on lettuce (Logan and Chaney, 1983).

The objectives of this study were to evaluate the applicability of the lettuce derived Zn phytotoxicity threshold to a range of other crops to evaluate the protectiveness of the Part 503 rule. In addition, the District often utilizes biosolids as a topsoil substitute or soil conditioner where biosolids are applied in very heavy loading rates. Biosolids users at these sites have had a tendency to be apprehensive about effects of biosolids metals on turf grass due to the high biosolids loading rates. The study also determines the phytotoxic threshold leaf Zn concentration for several varieties of turfgrass so that the likelihood of inducing Zn phytotoxicity in turf grasses planted at these sites can be evaluated.

MATERIALS AND METHODS

The studies described in this report were all conducted from 1997 through 1999 in the Lue-Hing R&D Complex greenhouse at the District's Stickney Water Reclamation Plant.

Soil Preparation, Sampling, and Analysis

The pulverized topsoil utilized in the study was of unknown origin and was acquired from a local topsoil vendor. The soil had a heavy texture and was blended three parts soil to one part sand to improve its tilth. The resulting blended soil had a loam texture (44 percent sand, 35 percent silt, and 21 percent clay), 1.04 percent organic carbon, 83 mg kg^{-1} total Zn concentration, and a pH of 6.7.

Reagent grade $ZnSO_4 \bullet 7H_2O$ was used to produce four series of eight Zn spiking levels. The four series of spiking levels were: Grass Series 1 (0, 125, 250, 500, 1000, 2000, 4000, and 8000 mg Zn kg^{-1} soil), Grass Series 2 (0, 250, 500, 1000, 2000, 3000, 4000, and 5000 mg Zn kg^{-1} soil), Vegetable Series 1 (0, 40, 80, 160, 320, 640, 1280, 2560 mg Zn kg^{-1} soil), and Vegetable Series 2 (0, 80, 160, 320, 460, 640, 960, and 1280 mg Zn kg^{-1} soil). All blending and mixing of soil and spiking chemicals was conducted in stationary cement mixers having 100 L polyethylene lined drums.

After each fresh spiking, soils were placed in 26.7 x 49.5 cm plastic pots for Vegetable Series 1 and 2 and in 22.9 x 38.1 cm plastic pots for Grass Series 1 and 2 (three replicate pots for each spiking level) and were moistened to field capacity and allowed to equilibrate for eight weeks prior to planting. After each trial the replicate pots were combined in the cement mixer and thoroughly mixed. A composite sample was collected at the time of mixing to verify that Zn spiking levels were not altered by watering during the previous test cycle.

Prior to each experimental cycle composite samples were taken from each soil treatment. Total Zn analysis was conducted by digesting duplicate 2.5 g samples in 7.5 mL of concentrated trace metal grade nitric acid (HNO_3) overnight at 100 °C. The samples were diluted to 75 mL and filtered prior to Zn analysis using inductively coupled plasma atomic absorption spectroscopy. Water soluble Zn analysis was conducted by extracting duplicate 20.0 g samples with 20 mL of ultrapure water (1 hour shake time). Samples were centrifuged and filtered prior to Zn analysis using inductively coupled plasma atomic absorption spectroscopy. Soil pH and electrical conductivity were analyzed on duplicate 20 g samples using a 1:1 slurry.

Plant Culture, Harvest, and Analysis

All plants tested in this study are listed in Table 1. They were all seeded directly into the potted spiked soils. The spiked soil series that were used to culture each of the plants used in this experiment are also listed in Table 1. Plants were cultured for four to ten weeks prior to harvest as indicated in Table 1. Two varieties of beet, Ruby Queen and Red Ball, were harvested twice during the study period. Shoots were harvested at 4 and 10 weeks.

At the end of the culture period, for each pot, the number of plants was recorded and all above ground tissue was harvested and washed with deionized water and mild phosphorus-free detergent solution. Leaves were separated from stems and the tissues were dried at 65°C. Dry weight of the en-

TABLE 1: LIST OF PLANT SPECIES TESTED IN THE ZINC PHYTOTOXICITY STUDY

Common Name	Scientific Name	Variety	Dates Tested[1]	Soil[2]
Beet	*Beta vulgaris*	Red Ball	Aug-Oct 1997 (4,10)	V1
Beet	*Beta vulgaris*	Ruby Queen	Aug-Oct 1997 (4,10)	V1
Beet	*Beta vulgaris*	Early Wonder	Aug-Oct 1997 (10)	V1
Bentgrass-creeping	*Agrostis stolonifera*	Penncross	Aug-Oct 1997 (7)	G1
Bluegrass-Kentucky	*Poa pratensis*	Banjo	Aug-Oct 1997 (9)	G1
Buffalo grass	*Buchloe Dactyloides*	unknown	April-June 1998 (9)	G2
Corn	*Zea mays*	Pioneer 3394	Jan-Mar 1999 (7)	G2
Cotton	*Gossypium hirsutum*	Acalla	Sep-Nov 1998 (8)	V2
Fescue-tall	*Festuca arundinacea Schreb*	Houndog	Dec 1997-Jan 1998 (7)	G2
Lettuce	*Lactuca sativa*	Black Seeded Simpson	Jan-Feb 1998 (6)	V2
Lettuce	*Lactuca sativa*	Black Seeded Simpson	Aug-Sep 1999 (6)	V2
Lettuce	*Lactuca sativa*	Iceberg	June-July 1999 (6)	V2
Oat	*Avena sativa*	Ogle	Dec 1998-Jan 1999 (6)	G2
Red top	*Agrostis alba*	Streaker	Feb-Mar 1998 (8)	G2
Reed canary grass	*Phalaris arundinacea*	unknown	Sep-Oct 1998 (6)	G2
Ryegrass-perennial	*Lolium perenne*	Essence	Nov 1997-Jan 1998 (6)	G2
Spinach	*Spinacea oleracea*	Bloomsdale longstanding	Oct-Dec 1997 (6)	V2
Tomato	*Lycopersicon esculentum*	Rutgers	May-July 1998 (6)	V2
Tomato	*Lycopersicon esculentum*	Rutgers	Feb-Mar 1999 (6)	V2
Wheat	*Triticum aestivum*	Madison	Nov 1998-Jan 1999 (6)	G2

[1] Numbers in parenthesis indicate length of test period in weeks prior to plant harvest.

[2] G1 = Zn spike levels of 0, 125, 250, 500, 1000, 2000, and 4000, and 8000 mg kg^{-1}; G2 = Zn spike levels of 0, 250, 500, 1000, 2000, 3000, 4000, and 5000 mg kg^{-1}

V1 = Zn spike levels of 0, 40, 80, 160, 320, 640, 1280, and 2560 mg kg^{-1}; V2 = Zn spike levels of 0, 80, 160, 320, 460, 640, 960, and 1280 mg kg^{-1}

tire shoot was recorded prior to grinding the leaf tissue in preparation for chemical analysis. Leaf tissues were prepared for trace element and macronutrient analysis by digesting duplicate 0.50 g samples in concentrated HNO_3 at 100°C overnight. Digests were analyzed for Zn, Cu, K, Ca, Mg, Fe, and Mn using inductively coupled plasma atomic absorption analysis. Where tissues were also analyzed for total Kjeldahl nitrogen (TKN) and total phosphorus content, duplicate 0.30 g samples of tissue were digested in concentrated sulfuric acid overnight using a copper/selenium catalyst at 350°C.

Statistical and Phytotoxicological Analysis

In this study two statistical tools were utilized to evaluate the effect of leaf Zn concentration on growth of various plant species. Plant growth, or dry matter production (mg plant^{-1}), and leaf chemical composition were determined for a variety of plant types grown in pots spiked with zinc at several dosage levels. Zinc dosage levels varied with plant type, but indexes of consecutive dosage levels are reported rather than the dosage level itself to emphasize the pattern of change in plant growth over adjacent zinc dosage levels rather than in terms of the actual amount of zinc spiked in the pots. The zero index level corresponds to a zero zinc dosage. The raw data are reported in <u>Appendix I</u>.

An initially constant one-knot spline model is used to estimate the phytotoxic threshold at which the level of zinc in plant tissue begins to have a toxic effect on plant growth. Adaptive grouping analysis is also used to estimate the highest no adverse effect and lowest observed adverse effect leaf Zn concentration levels. The results of the adaptive grouping analysis are presented in <u>Appendix II</u> and the relationship between plant dry matter production and leaf Zn concentration predicted by the one-knot spline model are displayed in figures in <u>Appendix III</u>.

Spline Analysis. It was desirable to develop a statistical method that could account for, or describe, the monotonic decay in plant growth that was expected to occur for increasing tissue zinc after a phytotoxic threshold was crossed. For this reason, an initially constant one-knot spline model was used to estimate the phytotoxic threshold at which the level of zinc in plant tissue begins to have a toxic effect on plant growth.

A leave-one-out likelihood cross-validation was used to select an initially constant one-knot spline model for plant growth (y) in terms of tissue zinc (x). Regression models with y normally distributed with constant variance are used with expected response

$$E(y|x) = \beta_0 + \beta_1 T(x, x_T)^p \qquad \underline{\text{Equation 1}}$$

where

$$T(x, x_T) = \begin{cases} 0 \text{ if } x \le x_T \\ x - x_T \text{ if } x > x_T \end{cases}$$

for the single knot x_T. The intercept parameter β_0 represents expected plant growth at the zero spiking level. The knot x_T represents the phytotoxic threshold at which leaf zinc concentration starts to have a negative effect on plant growth. Only nonnegative powers p are considered, and so the expected plant growth decreases after the phytotoxic threshold since estimates of associated slope parameters β_1 are all negative.

For a fixed choice of the phytotoxic threshold x_T, the best nonnegative power $p(x_T)$ is determined by maximizing the likelihood cross-validation score over $p \ge 0$. The associated score $LCV(x_T)$ is then maximized over selected choices of x_T. A starting value for x_T is determined by the average tissue zinc values in appropriate tables in Appendix I. For example, for Kentucky bluegrass, the average tissue zinc concentration is 359 mg kg^{-1} for the second highest spiking level grouped with the zero spiking level (Table AII-10). The next lower value, 350 mg kg^{-1} in this case, that is a multiple of 10 is used as the starting value for x_T and then the search proceeds over multiples of 10 greater than the starting value until the score $LCV(x_T)$ becomes less than 1 percent of the highest score so far. We determined a range of acceptable thresholds which is the largest contiguous interval about the best score threshold with LCV scores within 1% of the best score. Growth reduction levels of $\alpha \cdot 100$ percent equal to 10 percent, 25 percent, and 50 percent were also determined by solving for $E(y|x)$ equal to $(1-\alpha)\cdot\beta_0$ at the threshold for x_T with the best score.

The figures in Appendix III display the predicted plant growth over initial segments of tissue zinc concentrations for each plant type based on this spline model.

Adaptive Grouping Analysis. An adaptive grouping analysis was also conducted to provide an additional tool for assessing the phytotoxic threshold. This was accomplished by systematically merging data with adjacent zinc dosage levels in order to identify ranges of zinc causing constant expected plant growth. Analyses for all plant types were conducted using PROC IML™ in SAS® Version 8.00 with code implementing the methods described below. This analysis generated plots of the observed tissue dry matter data for each of the plant types together with predicted expected tissue dry matter values for adaptively grouped zinc dosage levels. These figures provide an indication of the number of initial zinc dosage levels for which the impact of Zn spiking on plant growth is similar to the zero dosage level. They also provide an indication of the progression of the phytotoxic effect that occurs as the zinc dosage level increases.

Special SAS macros were used for model selection based on a likelihood cross-validation approach similar to that of Knafl et al. (2004), but in the linear regression setting rather than the Poisson regression setting considered there. A standard one-way analysis of variance or single predictor regression context is assumed, that is, suppose n pairs (x_i,y_i) of values are sampled independently with conditional response $y|x$ normally distributed with expected value $E(y|x)$ and constant variance $VAR(y|x)=\sigma^2$. (For the zinc spiking data, response y is plant growth while x is the index of increasing spiking levels.) Assume further that the values of x are naturally ordered and that it is desired to determine groupings of adjacent observed x values over each of which the conditional expected value $E(y|x)$ is reasonably treated as constant, that is,

$$E(y/x = x_i) = E_j \text{ for } i_{j-1} < i \le i_j, 1 \le j \le J \qquad \text{Equation 2}$$

where

$$0 = i_o < i_1 < \ldots < i_{j-1} < i_{j-n} \ \ and \ \ x_1 \le x_2 \le \ldots \le x_{n-1} \le x_n$$

The appropriate number of groups J is unknown as are the indexes i_j which determine the grouping of x values into ranges $G_j=\left[x_{i_{j-1}}, x_{i_j}\right]$ for $1 \leq j \leq J$. Assume further, in order to simplify the notation, that observations with the same x values are always placed in the same groups.

Given a grouping $G=(G_1,\ldots,G_J)$, the assumption of constant expected value (Equation 2) for each and every group G_j determines the maximum likelihood estimates of those expected values. In the normally distributed, constant variance case, the estimated expected value for each group G_j is the average of the response values

$$\hat{E}_j = \frac{\sum_{i=i_{j-1}+1}^{i_j} Y_i}{n_j} \qquad \text{Equation 3}$$

for the $n_j=i_j-i_{j-1}$ observations in that group. The associated maximum likelihood estimate of the constant variance is given by

$$\hat{\sigma}^2 = \frac{\sum_{j=1}^{J} \sum_{i=i_{j-1}+1}^{i_j} \left(Y_i - \hat{E}_j\right)^2}{\sum_{j=1}^{J} n_j} \qquad \text{Equation 4}$$

where the denominator equals the sample size n. The unbiased estimate of variance is often used in place of the maximum likelihood estimate in which case the denominator is changed to the degrees of freedom n-J. When the sample size is large relative to the number of groups J, there is little difference between these two estimates.

A scoring criterion is needed in order to distinguish between groupings. The scoring criterion utilized in the method of this section is likelihood cross-validation (LCV) with larger values corresponding to better groupings. To be consistent with the use of a likelihood scoring criterion, the maximum likelihood estimate of variance is used instead of the unbiased estimate.

Under a full or leave-one-out type of cross-validation, the contribution to the LCV score for each observation (x_i,y_i) is the likelihood evaluated at its response value y_i, its x value, x_i, and the deleted estimates of the parameters computed using all the other observations. In the normally distributed, constant variance case, deleted estimates of the conditional expected value $E(y|x=x_i)$ and constant variance σ^2 need to be computed for each observation. General k-fold cross-validation is possible in which k subsets, called folds, of about the same size are deleted one at a time. Leave-one-out cross-validation is the special case with k set to the sample size and is used in the analyses of the plant growth data.

An algorithm is needed in order to search systematically through possible groupings since exhaustive search is impractical. Heuristics are needed to adapt the search to the data in a way that balances the need for extensive coverage of models with practical issues like limitations on time. An agglomerative algorithm systematically combining finer groupings into coarser groupings is used.

This algorithm may be described as follows. Start with an initially selected grouping with observations having the same x values combined into the same groups, one for each distinct observed x value. At each iteration, consider pairwise adjusted groupings determined from the currently selected grouping by combining each possible pair of adjacent groups leaving the other groups unchanged. The adjusted grouping formed from all pairwise adjusted groupings with LCV scores within a fixed tolerance (0.1 percent was used in this study) of the best pairwise adjusted grouping is the candidate for the next selected grouping. If the LCV score for this candidate adjusted grouping was no worse than a fixed tolerance (2 percent was used in this study) below the best score for all candidate groupings considered so far, it was set to the currently selected grouping and the search was continued. If not, the search was stopped and the current selected grouping was used as the final selected grouping. At each stage of the algorithm, there is at least one less group than at the previous stage, so either the algorithm stops because the next candidate for the selected grouping has too low a LCV score or else the currently selected grouping is eventually reduced to a single group. In the latter case, the algorithm stops and uses the overall constant model, that is, average response values for all the observations in the data set.

This search procedure is adaptive in the sense that it adapts to the data by utilizing groupings that are more consistent with the data as measured by LCV scores. It is also heuristic in the sense that it employs rules on how to adapt to the data. One of its rules is that groupings no worse than a fixed tolerance (2 percent was used in this study) below the best score so far are acceptable groupings even though their scores may not be optimal. This rule allows for the selection of more parsimonious groupings as long as the penalty is not too large and reflects the practical reality that the grouping with the numerically best score need not be the best practical choice. Another of its rules is to consider multiple pairwise adjusted groupings for the next iteration as long as their individual scores are close to best (within 0.1 percent of best was used in this study) rather than only those with the best score. This reduces the amount of computations and reflects the reality that grouped adjacent pairs with close to best scores in one iteration will tend to become pairs with the best scores in later iterations and so are reasonable to include in the selected grouping at an earlier stage of the computation.

RESULTS AND DISCUSSION

Phytotoxic thresholds determined for the vegetable and grass species utilized in this study are reported in Table 2. In addition to phytotoxic thresholds, Table 2 also contains intervals of acceptable values for those thresholds with likelihood cross-validation scores (see Adaptive Grouping section of Materials and Methods) within 1% of the score for the estimated threshold, and estimates of leaf zinc concentrations at which 10%, 25%, and 50% growth reduction occur.

Effect of Plant Age on Phytotoxic Zn Threshold Determination

In this study plants were grown in Zn spiked soils for four to ten weeks prior to harvest. The duration of the growth period was determined by the species specific growth rate and the time of year the trial was conducted. Generally, plants with slower rates of dry matter production (e.g. slow germinating grasses) and trials conducted during late fall, winter, and early spring months were conducted for longer time periods than trials conducted during late spring, summer and early fall months for species with rapid dry matter production rates.

Other studies conducted to date, which have utilized short duration experimental periods (four to six weeks) have been criticized in the scientific literature as being not representative of phytotoxic effects that can be manifested during a full life cycle in the field (Schmidt, 1997; McBride, 1995). Concerns include the question of whether sensitivity to Zn changes during the life cycle. To address this we determined the phytotoxic Zn threshold for two varieties of beet after four weeks of growth (immature seedlings) and at plant maturity (10 weeks of growth).

The estimated phytotoxic Zn threshold for Red Ball variety beet was determined to be 240 mg kg^{-1} for plants that were 4 weeks old and 430 mg kg^{-1} for plants that were 10 weeks old (Table 2). For Ruby Queen variety beets the phytotoxic Zn threshold was also determined to be 240 mg kg^{-1} for plants that were four weeks old and 930 mg kg^{-1} for plants that were 10 weeks old (Table 2). These results indicate that beets become less sensitive to Zn phytotoxicity as it matures. This suggests that short term study durations (harvesting plants prior to maturity) is a conservative method of estimating the phytotoxic Zn threshold.

Temporal and Varietal Variability in Phytotoxic Zn Threshold

In order to test the question of applicability of a phytotoxic threshold to various varieties or cultivars of a species and to determine reproducibility of this methodology for determining phytotoxic Zn thresholds we grew three varieties of beet simultaneously and two cultivars of lettuce. We also conducted the trial on tomato and Black Seeded Simpson variety lettuce in 1998 and repeated it in 1999.

The estimated phytotoxic Zn thresholds determined for the three varieties of beet were 1010, 430, and 930 mg kg^{-1} for Early Wonder, Red Ball, and Ruby Queen varieties, respectively. The ranges of acceptable thresholds overlapped for Early Wonder and Ruby Queen but Red Ball had a significantly lower phytotoxic Zn threshold than the other two varieties (Table 2).

The estimated phytotoxic Zn thresholds determined for Iceberg and Black Seeded Simpson lettuce in 1999 were 380 and 230 mg kg^{-1}, respectively. The ranges of

TABLE 2: ESTIMATED LEAF PHYTOTOXIC ZN THRESHOLDS DETERMINED FOR GRASSES, CEREALS AND GRAINS, AND VEGETABLES

Plant Type[1]	Estimated Threshold[2]	Acceptable Threshold[3]	Estimated Leaf Zn Concentration at Growth Reduction of 10%	25%	50%
	---mg kg^{-1}---				
Beet-EW (Leaves-10 Wks)	1010	740-1460	1013	1042	1194
Beet-RB (Leaves-4 Wks)	240	210-470	240	244	415
Beet-RB (Leaves-10 Wks)	430	430-440	432	457	636
Beet-RQ (Leaves-4 Wks)	240	230-240	240	240	258
Beet-RQ (Leaves-10 Wks)	930	870-1180	930	930	935
Buffalo Grass	930	930-990	931	958	1260
Corn	560	560-560	560	569	928
Cotton	440	430-440	440	442	486
Creeping bentgrass	300	290-300	326	543	1619
Kentucky Bluegrass	690	620-770	690	690	713
Lettuce-Iceberg	380	370-380	385	413	517
Lettuce-BSS (1998)	130	70-150	154	249	531
Lettuce-BSS (1999)	230	230-260	255	334	532
Oat	970	950-980	973	1088	2851
Perennial Ryegrass	1150	1130-1150	1151	1186	1873
Red Top	460	370-460	464	529	1021
Reed Canary Grass	1520	1390-1530	1520	1527	1855
Spinach	720	710-720	720	734	924
Tall Fescue	1250	1200-1250	1252	1359	2508
Tomato (1998)	420	370-470	420	423	863
Tomato (1999)	420	420-470	423	439	504
Wheat	550	440-570	606	1099	3654

[1] EW = Early Wonder, RB = Red Ball, RQ = Ruby Queen, BSS = Black Seeded Simpson

[2] Leaf Zn value with best LCV score searching among multiples of 10 starting at the average tissue Zn value for the largest level grouped with the zero level after rounding it to a multiple of 10 with the search in both directions continuing until a score occurs that is less than 1% of the best score so far.

[3] Largest contiguous interval about the estimated threshold of multiples of 10 with LCV scores within 1% of the score for the estimated threshold.

acceptable thresholds did not overlap for these two cultivars (Table 2).

The estimated phytotoxic Zn thresholds determined for Black Seeded Simpson lettuce grown in 1998 and 1999 were 130 and 230 mg kg^{-1} respectively. The ranges of acceptable thresholds did not overlap for these two trials (Table 2).

The estimated phytotoxic Zn thresholds determined for tomato grown in 1998 and 1999 were 420 and 420 mg kg^{-1} respectively (Table 2).

These results indicate that phytotoxic Zn thresholds can vary significantly among cultivars or varieties of the same species. This methodology for assessing phytotoxic Zn thresholds can have significant temporal variability although it does not consistently occur. The cause of this temporal variability is not known.

Evaluation of Part 503 Phytotoxic Zn Threshold

The USEPA utilized a phytotoxic threshold of 400 mg Zn kg^{-1} leaf tissue in their Part 503 risk assessment. We used the results of this study to evaluate the applicability of this threshold to vegetable and fiber crops and species in the grass family which included turf species, vegetative cover crops, native range grass, and cereal and grain crops. For the purposes of this evaluation only data for beet grown for 10 weeks were used since they were generated from mature plants.

In this study, four species were determined to have phytotoxic Zn thresholds greater than 1000 mg Zn kg^{-1} leaf tissue. These were beet (v. Early Wonder), perennial ryegrass, reed canary grass, and tall fescue. Their phytotoxic Zn thresholds were determined to be 1010, 1150, 1520, and 1250 mg Zn kg^{-1} leaf tissue, respectively. The lower bounds of the acceptable range of thresholds for these four species were all above 700 mg Zn kg^{-1} leaf tissue (Table 2).

An additional five species had estimated phytotoxic Zn thresholds greater than 600 mg Zn kg^{-1} leaf tissue. These were beet (v. Ruby Queen), buffalo grass, Kentucky bluegrass, oat, and spinach. Their phytotoxic Zn thresholds were determined to be 930, 930, 690, 970, and 720 mg Zn kg^{-1} leaf tissue, respectively. The lower bounds of the acceptable range of thresholds for these five species were all above 600 mg Zn kg^{-1} leaf tissue.

An additional six species had phytotoxic Zn thresholds greater than the Part 503 threshold of 400 mg Zn kg^{-1} leaf tissue. These were beet (v. Red Ball), corn, cotton, red top, tomato grown in 1998 and in 1999, and wheat. Their phytotoxic Zn thresholds were determined to be 430, 560, 440, 460, 420, and 420 and 550 mg Zn kg^{-1} leaf tissue, respectively. The lower bounds of the acceptable range of thresholds for all of these species except red top and tomato (grown in 1998) were above the Part 503 phytotoxic threshold of 400 mg Zn kg^{-1} leaf tissue.

The lower bound of the acceptable threshold range for both red top and tomato grown in 1998 was determined to be 370 mg Zn kg^{-1} leaf tissue (Table 2). This lower bound is below the Part 503 phytotoxic Zn threshold. To further evaluate the phytotoxic threshold we conducted adaptive grouping analysis for all of the species that were tested (Appendix II). Tables 3 and 4 present the results of grouping analysis for red top and tomato. The first column of these tables, labeled index of dosage level, relates the soil Zn spiking level imposed on the plants (Table 1) with 0 being the control and Zn spiking concentration increasing with increasing

TABLE 3: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR RED TOP, VARIETY STREAKER, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg plant^{-1})
0	0	64.0	71.8
1	0	64.0	438
2	1	37.8	676
3	1	37.8	843
4	2	14.9	2871

TABLE 4: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR TOMATO, VARIETY RUTGERS, GROWN IN 1998 INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Mean Leaf Zinc Concentration (mg plant^{-1})
0	0	2726	57.0
1	0	2726	128
2	0	2726	143
3	0	2726	188
4	0	2726	493
5	0	2726	443
6	1	371.3	1026
7	1	371.3	1563

index number. The second column, labeled group index, indicates which dosage levels are grouped together (i.e. which Zn dosages produced plants with mean dry matter not significantly different from each other). Dosages with the same group index produced plants with dry matter not significantly different. Group 0 includes all treatments (Zn dosage levels) that did not show a significant phytotoxic Zn effect (i.e. no significant reduction in shoot dry matter with respect to the control). The third column displays the mean plant dry matter estimated for the group of dosage levels by the grouping model and the last column displays the mean leaf Zn concentration for plants from each dosage level from which plants were harvested.

Table 3 shows that dosage levels 0 and 1 were included together in Group 0 indicating that statistical analysis found dry matter to be not significantly different for red top grown in control soil or in soil spiked at the first Zn dosage level. Therefore Zn dosage level 1 produced no phytotoxic effect and had mean leaf Zn concentration of 438 mg kg^{-1}, which is above the Part 503 phytotoxic Zn threshold. Phytotoxic Zn effects are first observed for red top in plants from dosage level 2, Group 1, and they had average leaf Zn concentrations of 676 mg kg^{-1} which is well above the Part 503 phytotoxic threshold of 400 mg Zn kg^{-1} tissue. It therefore appears that the phytotoxic Zn threshold for red top lies above the Part 503 threshold of 400 mg kg^{-1}.

Table 4 shows that dosage levels 0 through 5 were included together in Group 0 for Tomato grown in 1998. Therefore Zn dosage levels 4 and 5 produced no phytotoxic effect and had mean leaf Zn concentrations of 493 and 443 mg kg^{-1}, respectively. These are above the Part 503 phytotoxic Zn threshold. Phytotoxic Zn effects are first observed for tomato grown in 1998 in plants from dosage level 6, Group 1, and they had average leaf Zn concentrations of 1026 mg kg^{-1} which is far above the Part 503 phytotoxic threshold of 400 mg Zn kg^{-1} tissue. Based on this and the observation that the lower limit of the acceptable phytotoxic threshold range for tomato grown in 1999 was 420 mg Zn kg^{-1} tissue, it therefore appears that the phytotoxic Zn threshold for tomato lies above the Part 503 threshold of 400 mg kg^{-1}.

The lettuce varieties and the creeping bentgrass that were tested in this study all had estimated phytotoxic Zn thresholds below the Part 503 threshold of 400 mg kg^{-1}. The estimated phytotoxic Zn threshold for creeping bentgrass, Iceberg variety lettuce, and Black Seeded Simpson variety lettuce grown in 1998 and 1999 were determined to be 300, 380, 130, and 230 mg Zn kg^{-1} plant tissue. The range of acceptable thresholds for these species were all below 400 mg Zn kg^{-1} plant tissue (Table 2).

The estimated threshold for iceberg lettuce, 380 mg kg^{-1}, is very close to the Part 503 threshold. Since spline modeling in this study estimates that leaf Zn concentration of 413 mg kg^{-1} produces a 25 percent growth reduction (Table 2), allowing Zn to accumulate in the leaves of this plant species up to the Part 503 Zn phytotoxic threshold of 400 mg kg^{-1} may produce a growth reduction, but it should be less than 25 percent.

The spline model in this study estimated the phytotoxic Zn threshold for creeping bentgrass to be 300 mg kg^{-1}, and that 326 mg kg^{-1} will produce a 10 percent growth reduction while 543 mg kg^{-1} is required for a 25 percent growth reduction. Thus, allowing Zn to accumulate in the leaves of this plant species up to the Part 503 phytotoxic Zn threshold may produce a growth reduction, but it should be less than 25 percent.

The results of this study are not as clear-cut for Black Seeded Simpson variety of lettuce because it was tested twice and the results of the two trials were not consistent. The results of this study indicate that the estimated phytotoxic threshold is 130 and 230 mg kg^{-1} for the 1998 and 1999 trials, respectively. Allowing Zn to accumulate in the leaves of this plant species up to the Part 503 phytotoxic Zn threshold will likely produce a growth reduction. According to the results of spline modeling for both trials in Table 2, a leaf Zn concentration of 400 mg kg^{-1} should result in a growth reduction of between 25 and 50 percent. The grouping analysis for the 1998 trial indicated that dosage levels 0, 1, and 2 were all included in Group Index 0 (Table 5). Significant growth reduction was not observed at dosage level 2 which had mean leaf Zn concentration of 227 mg kg^{-1} but was observed at dosage level 3 which had an average leaf Zn concentration of 483 mg kg^{-1} (Table 5). For the 1999 trial, grouping analysis indicated that dosage levels 0, 1, 2, and 3 produced equivalent dry matter (Table 6). Growth reduction did not occur at dosage level 3 which had mean leaf Zn concentration of 223 mg kg^{-1} but was observed at dosage level 4 which had an average leaf Zn concentration of 321 mg kg^{-1} (Table 6). The phytotoxic Zn threshold is likely between 220 and 320 mg kg^{-1} for this variety of lettuce. The study corroborates the Part 503 assumption that lettuce is the most sensitive species to Zn and illustrates that small growth reductions can result in some varieties of lettuce if Zn concentration in leaves is allowed to rise to the Part 503 threshold.

Determination of Zn Phytotoxicity in Turf Grasses

This study determined phytotoxic Zn thresholds for turf grasses including: Kentucky bluegrass, perennial ryegrass, tall fescue, creeping bentgrass, and red top. In addition, buffalo grass and reed canary grass were also tested. The estimated phytotoxic Zn threshold for these grasses ranged from 300 mg kg^{-1} for creeping bentgrass to 1520 mg kg^{-1} for reed canary grass. The turfgrasses from the genera *Agrostis* (creeping bentgrass and red top) were the most sensitive.

For diagnostic purposes, the phytotoxic leaf Zn concentration for each grass species tested can be set to the concentration producing 25 percent growth reduction rounded to two significant figures. Table 7 displays these thresholds. For turf grasses grown in District biosolids in greenhouse pots or in the field, concentrations of Zn in leaves of the turf have never approached the thresholds in Table 7. For instance, Granato et al. (1998) reported that the mean concentration of Zn in leaves of two Kentucky bluegrass varieties, a creeping bentgrass, an Idaho bentgrass, a red top, an alkali grass, and four tall fescue varieties was 162 mg kg^{-1} when the plants were grown in 100 percent biosolids in pots in the greenhouse. Since plants grown in greenhouse pots show greater uptake rates of metals than plants grown under field conditions it therefore does not seem likely that Zn in the District's biosolids will ever induce phytotoxicity in turf even when biosolids are used as topsoil.

TABLE 5: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR LETTUCE, VARIETY BLACK SEEDED SIMPSON, GROWN IN 1998 INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg $plant^{-1}$)
0	0	104.6	40.5
1	0	104.6	171
2	0	104.6	227
3	1	57.9	483
4	2	28.8	605
5	2	28.8	1148
6	3	4.99	1455

TABLE 6: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR LETTUCE, VARIETY BLACK SEEDED SIMPSON, GROWN IN 1999 INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg $plant^{-1}$)
0	0	1367	108
1	0	1367	107
2	0	1367	165
3	0	1367	223
4	1	941	321
5	1	941	443
6	2	344	682
7	3	26.4	1130

TABLE 7: LEAF ZN CONCENTRATION THRESHOLDS TO DETERMINE PHYTOTOXICITY IN GRASSES

Grass Species	Phytotoxic Zn Threshold
	mg kg^{-1}
Creeping bentgrass	490
Red top	530
Kentucky bluegrass	690
Buffalo grass	960
Perennial ryegrass	1190
Reed canary grass	1530
Tall fescue	9710

REFERENCES

Granato, T. C., R. I. Pietz, O. Dennison, P. Tata, D. R. Zenz, and C. Lue-Hing, An Evaluation of the Suitability of Grass Species and Varieties for Germination and Growth in Biosolids, Research and Development Department Report 98-26, Metropolitan Water Reclamation District of Greater Chicago, 1998.

Knafl, G. J., K. P. Fennie, C. Bova, K. Dieckhaus, and A. B. Williams, "Electronic monitoring device modeling on an individual-subject basis using adaptive Poisson regression," Statistics in Medicine 23:783-801, 2004.

Logan, T. J., and R. L. Chaney, "Utilization of Municipal Wastewater and Sludges on Land-Metals," pp. 235-323, In Proceedings of the 1983 Workshop on Utilization of Municipal Wastewater and Sludge on Land, A. L. Page, T. L. Gleason, J. E. Smith, I. K. Iskandar, and L. E. Sommers (eds.), University of California, Riverside, California, 1983.

McBride, M. B., "Toxic metal accumulation from agricultural use of sludge: are USEPA regulations protective?", Journal of Environmental Quality 24: 5-18, 1995.

Schmidt, J. P., "Understanding phytotoxicity thresholds for trace elements in land-applied sewage sludge," Journal of Environmental Quality 26:4-10, 1997.

United States Environmental Protection Agency (USEPA), Technical Support Document for Land Application of Sewage Sludge, Volume I (PB93-110575), Office of Water, November 2002.

APPENDIX I

PLANT DRY MATTER PRODUCTION AND LEAF CONCENTRATIONS OF ZINC, COPPER, POTASSIUM, CALCIUM, MAGNESIUM, MANGANESE, IRON, NITROGEN, AND PHOSPHORUS

TABLE AI-1: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BEET, VARIETY EARLY WONDER, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Leaf Zn (mg/kg)
1	0	5033.5	46.54
2	1	3235.7	197.29
3	1	1580.0	177.83
4	2	4183.0	217.36
5	3	3821.0	504.29
6	4	3155.4	820.02
7	4	1796.6	658.58
8	5	14.0	2053.57
9	5	881.0	1467.77

TABLE AI-2: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BEET, VARIETY EARLY WONDER, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	7.6380	73425.00	17156.75	19585.13	181.938	68.500	NA	NA
2	6.5630	72375.00	13204.75	25910.38	132.663	97.250	NA	NA
3	9.5160	82562.50	12915.00	19542.97	83.359	69.375	NA	NA
4	8.1880	81750.00	12618.25	14979.88	70.588	89.250	NA	NA
5	7.9630	65225.00	16575.75	28405.88	126.238	69.000	NA	NA
6	7.2345	62736.88	16440.00	26786.72	79.578	49.063	NA	NA
7	11.6410	83500.00	14800.63	17914.84	63.734	205.000	NA	NA
8	40.5840	48766.23	37207.79	21217.53	95.779	<0.400	NA	NA
9	9.1550	44627.59	22699.17	23618.00	182.754	125.519	NA	NA

NA: No analysis

TABLE AI-3: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BEET, VARIETY RED BALL, FOUR WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	169.333	53.25
2	0	112.000	46.59
3	0	233.750	51.40
4	1	62.286	108.66
5	1	169.500	100.90
6	1	149.000	99.30
7	2	35.250	121.26
8	2	132.250	115.98
9	2	141.000	130.90
10	3	330.667	207.40
11	3	119.000	300.38
12	3	185.000	219.20
13	4	131.000	477.00
14	4	59.000	1262.95
15	4	120.000	755.00
16	5	13.000	2148.99
17	5	16.500	1580.46
18	5	29.500	719.47
19	6	6.385	4297.13
20	6	10.182	2004.06
21	6	6.250	9603.60

TABLE AI-4: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BEET, VARIETY RED BALL, FOUR WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	12.3750	104375.00	9325.00	17275.00	93.500	91.250	NA	NA
2	9.7940	91058.82	7729.41	14602.94	80.912	120.000	NA	NA
3	11.3000	102600.00	9160.00	16250.00	88.900	172.000	NA	NA
4	15.2740	127959.18	12889.03	21999.11	92.027	183.750	NA	NA
5	10.9000	100600.00	10560.00	17150.00	60.500	129.000	NA	NA
6	11.4000	100000.00	11660.00	18150.00	61.600	124.000	NA	NA
7	13.2350	125798.00	14067.23	22626.05	69.454	121.008	NA	NA
8	9.5405	83521.19	9961.36	13745.97	49.022	126.026	NA	NA
9	9.9000	85900.00	11060.00	14850.00	50.800	127.000	NA	NA
10	11.8000	93200.00	12260.00	17450.00	51.600	99.000	NA	NA
11	16.1250	127375.00	12700.00	22312.50	60.250	128.750	NA	NA
12	10.3000	96600.00	9760.00	17650.00	45.300	160.000	NA	NA
13	6.2380	73567.96	15128.54	19145.63	55.721	156.398	NA	NA
14	12.0470	99222.80	35181.35	34650.26	142.098	160.622	NA	NA
15	9.1250	63750.00	23450.00	22437.50	72.125	667.500	NA	NA
16	12.3740	67171.72	43838.38	30176.77	81.566	196.970	NA	NA
17	11.1360	48636.36	30363.64	21250.00	97.955	490.909	NA	NA
18	3.0260	28684.21	13894.74	10197.37	31.447	123.684	NA	NA
19	9.1880	52500.00	31425.00	20156.25	81.563	566.250	NA	NA
20	6.0850	22924.53	14377.36	9834.91	105.991	387.736	NA	NA
21	17.4000	102000.00	65760.00	44100.00	177.000	768.000	NA	NA

NA: No analysis

TABLE AI-5: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BEET, VARIETY RED BALL, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	6568.0	29.66
2	0	5523.0	51.79
3	0	4529.0	60.24
4	1	6664.0	140.56
5	1	7516.0	98.04
6	1	5490.0	155.86
7	2	4641.0	191.96
8	2	5730.8	212.81
9	2	3763.0	104.11
10	3	4342.0	353.36
11	3	6098.0	426.36
12	3	5480.0	390.96
13	4	3698.4	833.49
14	4	2112.1	475.38
15	4	4053.5	648.76
16	5	96.8	1467.78
17	5	170.0	1054.02
18	5	349.7	1966.61

TABLE AI-6: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BEET, VARIETY RED BALL, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	3.625	69157.13	14177.50	34141.25	118.975	86.63	NA	NA
2	8.975	73182.13	13859.00	31216.25	112.450	78.13	NA	NA
3	8.725	81019.63	15900.50	20743.50	127.925	49.38	NA	NA
4	6.100	58882.13	12867.00	30641.25	114.350	339.63	NA	NA
5	4.950	61757.13	13834.50	19004.75	67.425	67.38	NA	NA
6	5.325	87374.63	17762.50	17257.50	95.100	57.63	NA	NA
7	8.250	93482.13	18834.00	17640.75	77.075	103.63	NA	NA
8	6.725	80457.13	10528.75	27142.25	74.125	60.13	NA	NA
9	5.725	74984.63	16599.50	19905.00	33.075	72.38	NA	NA
10	2.925	69132.13	10182.75	27691.25	70.400	79.38	NA	NA
11	5.775	85507.13	15252.25	24107.75	79.800	71.13	NA	NA
12	6.850	65189.88	17823.00	33085.50	70.250	61.88	NA	NA
13	5.700	68007.13	21944.50	26866.25	96.525	47.38	NA	NA
14	6.850	61104.75	27000.00	18470.50	94.750	77.75	NA	NA
15	7.725	39420.88	18272.00	29139.25	57.925	58.13	NA	NA
16	4.662	22970.29	48085.01	27688.30	55.667	56.22	NA	NA
17	8.231	3897.19	32499.35	6800.84	344.448	6290.99	NA	NA
18	10.527	25436.63	33036.57	19279.32	121.164	398.27	NA	NA

NA: No analysis

TABLE AI-7: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BEET, VARIETY RUBY QUEEN, FOUR WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	122.250	75.88
2	0	161.250	57.20
3	0	175.750	62.10
4	1	285.500	93.60
5	1	164.000	110.60
6	1	213.000	86.70
7	2	84.500	157.94
8	2	126.750	166.63
9	2	140.250	118.60
10	3	221.000	223.80
11	3	163.000	240.30
12	3	131.000	225.95
13	4	59.500	784.25
14	4	61.750	445.53
15	4	77.250	527.75
16	5	21.750	927.88
17	5	19.250	1194.66
18	5	17.250	1320.92
19	6	8.615	1574.07
20	6	6.700	3799.32
21	6	8.222	4504.23

TABLE AI-8: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BEET, VARIETY RUBY QUEEN, FOUR WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	9.3750	82625.00	8000.00	13000.00	49.375	115.000	NA	NA
2	12.1000	100000.00	10200.00	13800.00	68.500	140.000	NA	NA
3	6.1000	106000.00	9800.00	14200.00	36.500	52.500	NA	NA
4	8.3000	78600.00	8300.00	13700.00	36.000	93.000	NA	NA
5	11.9000	103700.00	11400.00	15400.00	43.600	157.000	NA	NA
6	10.0000	86200.00	9360.00	10560.00	39.940	143.400	NA	NA
7	<2.0000	56590.75	8345.89	7462.33	30.784	321.909	NA	NA
8	12.0000	111625.00	14500.00	19000.00	57.375	133.750	NA	NA
9	12.6000	90400.00	10100.00	17100.00	39.200	238.000	NA	NA
10	11.5000	106000.00	11500.00	14700.00	40.300	103.000	NA	NA
11	7.3000	76300.00	10300.00	13600.00	47.200	93.000	NA	NA
12	11.2865	100960.52	10886.70	13681.55	35.255	221.917	NA	NA
13	11.2500	106750.00	22000.00	21750.00	63.750	118.750	NA	NA
14	5.6350	56685.08	12430.94	11933.70	35.801	62.155	NA	NA
15	8.7500	99750.00	15500.00	12750.00	67.000	333.750	NA	NA
16	10.2350	99529.41	29647.06	26117.65	78.353	135.882	NA	NA
17	4.5210	40684.93	25068.49	15616.44	58.356	113.014	NA	NA
18	6.4620	36923.08	31384.62	18000.00	97.385	906.923	NA	NA
19	3.9820	44867.26	32654.87	18584.07	53.628	128.761	NA	NA
20	4.1100	50547.95	27123.29	15205.48	52.192	330.822	NA	NA
21	5.0700	67183.10	35915.49	20704.23	169.437	538.732	NA	NA

NA: No analysis

TABLE AI-9: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BEET, VARIETY RUBY QUEEN, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	2642.0	37.13
2	0	2503.0	41.13
3	0	3132.0	54.09
4	1	2646.0	189.10
5	1	2537.0	224.47
6	1	2131.0	156.94
7	2	3538.0	169.80
8	2	2709.9	216.79
9	2	975.0	115.70
10	3	706.0	406.80
11	3	1931.0	386.25
12	3	1197.0	246.80
13	4	1910.0	866.75
14	4	2216.6	844.20
15	4	1313.2	933.00
16	5	16.9	1418.18
17	5	96.9	2106.03

TABLE AI-10: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BEET, VARIETY RUBY QUEEN, TEN WEEKS FOLLOWING PLANTING IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	8.4250	48128.63	12175.63	32272.00	205.100	65.875	NA	NA
2	7.5250	87848.63	12083.13	29147.00	248.475	39.125	NA	NA
3	7.3125	94185.78	11006.72	27933.75	278.282	47.032	NA	NA
4	5.7250	87673.63	10794.88	30722.00	150.800	74.375	NA	NA
5	8.6875	95842.03	16037.03	40058.75	201.282	79.532	NA	NA
6	8.3130	104123.28	14525.78	33121.25	158.438	119.219	NA	NA
7	7.6250	82248.63	13473.13	37597.00	74.375	144.875	NA	NA
8	5.6785	90748.04	13814.82	32495.71	113.786	58.036	NA	NA
9	11.3000	97797.25	10608.25	19179.00	55.100	232.750	NA	NA
10	9.3000	79878.25	11024.25	23206.00	97.300	127.750	NA	NA
11	7.7500	105647.25	10753.25	27218.50	81.400	58.750	NA	NA
12	13.2000	68851.25	16376.25	21039.00	64.700	282.750	NA	NA
13	9.4500	72156.25	16977.25	23774.50	90.550	69.250	NA	NA
14	5.8500	55183.75	22309.25	28122.00	131.550	47.750	NA	NA
15	6.2500	50326.88	24911.04	28626.67	100.000	92.292	NA	NA
16	32.7270	17604.55	46731.82	22309.09	52.727	177.273	NA	NA
17	60.3020	19541.46	46179.65	26020.10	150.754	554.020	NA	NA

NA: No analysis

TABLE AI-11: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF BUFFALO GRASS PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	602.727	62.25
2	0	804.583	70.45
3	0	597.350	96.15
4	1	351.053	516.95
5	1	533.333	488.70
6	1	608.077	489.80
7	2	355.875	1239.45
8	2	865.545	923.50
9	2	579.167	1029.80
10	3	179.250	1021.70
11	3	229.636	2092.25
12	3	192.750	1652.50
13	4	23.571	4411.44
14	4	14.545	5032.19
15	4	22.273	3496.30

TABLE AI-12: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF BUFFALO GRASS PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	6.825	19194.50	4179.50	2413.50	68.400	79.500	22593.75	3550
2	4.825	22004.50	4774.00	2686.50	126.150	78.000	30093.75	3575
3	5.975	18615.00	4953.50	2753.00	163.050	115.500	27093.75	2725
4	5.825	21606.50	4578.50	2784.00	73.250	109.500	28793.75	3725
5	7.525	24351.50	5299.00	3204.00	103.550	94.000	31631.25	3950
6	6.175	20428.00	5463.50	3090.00	75.000	110.000	29381.25	3875
7	6.575	18399.50	5460.00	3462.00	90.500	134.000	27768.75	3575
8	6.325	21876.50	4767.50	3163.00	68.900	78.000	25606.25	3525
9	4.525	18890.00	4252.50	3118.50	76.200	89.000	27481.25	2925
10	14.175	26586.50	8410.00	5790.50	84.900	129.500	41831.25	6325
11	7.725	17771.00	5021.50	3889.50	130.300	131.500	28506.25	3100
12	7.425	19310.00	5758.00	4374.50	121.850	95.000	32568.75	3875
13	6.781	12794.12	7235.29	4926.47	74.673	197.712	NA	NA
14	4.024	10208.90	7061.64	5375.00	144.349	166.096	NA	NA
15	2.951	11078.70	6131.94	4098.38	95.023	112.269	NA	NA

NA: No analysis

TABLE AI-13: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF CORN PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	2643.33	33.68
2	0	3000.00	42.63
3	0	2500.00	41.08
4	1	2636.67	120.63
5	1	2958.33	100.38
6	1	2786.67	111.18
7	2	3180.00	234.03
8	2	3321.67	238.48
9	2	2936.67	260.13
10	3	2306.67	567.93
11	3	2158.33	691.38
12	3	2170.00	645.83
13	4	948.33	1526.88
14	4	886.67	963.98
15	4	891.67	1305.48
16	5	358.75	8086.98
17	5	450.00	5878.83
18	5	557.50	7883.98
19	6	264.44	15160.06
20	6	290.00	10952.47
21	6	239.00	11987.47

TABLE AI-14: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF CORN PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	7.050	34595.75	2969.50	3476.25	51.325.	69.750	NA	NA
2	8.100	33269.75	2879.50	3819.75	44.825	83.750	NA	NA
3	7.450	38428.75	3350.50	4302.25	55.375	81.750	NA	NA
4	7.150	44300.75	3685.50	3301.75	87.625	69.750	NA	NA
5	8.000	41019.25	2898.50	2792.25	81.875	62.750	NA	NA
6	7.400	39537.25	3653.00	3390.75	88.125	71.250	NA	NA
7	8.300	40932.75	3525.50	3200.75	84.325	62.250	NA	NA
8	7.150	38610.75	3117.00	3290.75	85.175	65.250	NA	NA
9	8.450	40125.75	4057.00	2739.75	87.425	74.250	NA	NA
10	6.850	44124.25	4068.50	3334.25	86.675	66.750	NA	NA
11	6.350	41143.25	4454.50	3752.25	86.525	71.750	NA	NA
12	6.350	41844.75	4766.50	2795.25	91.175	66.750	NA	NA
13	4.400	35662.75	5829.00	4920.75	169.725	53.750	NA	NA
14	4.250	40945.75	5190.50	3969.75	98.675	60.250	NA	NA
15	5.050	43281.75	5759.00	4764.75	122.375	108.250	NA	NA
16	5.400	44207.25	5751.00	6263.75	475.225	46.250	NA	NA
17	5.800	43147.25	5121.50	5872.25	428.125	56.750	NA	NA
18	6.500	43824.25	5631.50	6584.25	466.575	50.250	NA	NA
19	7.297	43126.29	6379.25	7365.84	510.425	49.338	NA	NA
20	5.250	48013.25	5004.00	5504.75	429.375	35.750	NA	NA
21	6.300	49230.75	5924.00	6493.25	481.275	48.750	NA	NA

NA: No analysis

TABLE AI-15: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF COTTON PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	1585.50	48.45
2	0	1408.00	52.95
3	0	1291.25	52.45
4	1	1612.80	57.55
5	1	1713.00	61.75
6	1	1321.00	65.70
7	2	1510.00	72.25
8	2	1375.75	79.55
9	2	1487.50	86.95
10	3	1730.25	136.05
11	3	1625.25	137.70
12	3	1000.00	151.15
13	4	1207.50	308.40
14	4	1407.50	289.10
15	4	1287.75	289.35
16	5	894.50	494.90
17	5	1102.50	440.30
18	5	822.75	551.40
19	6	243.00	773.95
20	6	194.00	598.95
21	6	243.00	702.95
22	7	162.50	901.96
23	7	108.25	1130.24
24	7	175.00	1241.69

TABLE AI-16: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF COTTON PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	5.675	31926.75	42973.25	13180.50	85.925	70.500	NA	NA
2	6.525	31821.25	43003.25	12982.50	85.425	70.000	NA	NA
3	4.725	31488.25	44192.75	12213.00	89.775	89.500	NA	NA
4	5.625	29863.75	43363.75	14267.50	85.575	68.000	NA	NA
5	5.325	32978.25	45302.75	12287.00	89.725	84.500	NA	NA
6	4.675	32271.75	44524.75	12750.50	107.475	91.500	NA	NA
7	4.525	27931.25	40102.75	14959.50	92.425	60.000	NA	NA
8	5.275	29384.75	43355.25	14211.00	106.425	88.000	NA	NA
9	4.525	30955.75	44958.75	12910.00	109.675	85.500	NA	NA
10	5.525	30350.25	41980.75	15320.00	106.325	59.500	NA	NA
11	4.725	34645.25	43805.25	13439.00	137.525	93.500	NA	NA
12	5.125	31897.25	49198.25	13673.50	128.875	83.000	NA	NA
13	4.125	29371.25	51844.75	14429.50	124.625	54.500	NA	NA
14	3.925	31657.25	47123.75	14345.00	118.675	66.500	NA	NA
15	3.875	31481.25	43839.75	13620.50	129.575	61.500	NA	NA
16	3.625	31695.25	49382.75	15410.00	162.175	51.500	NA	NA
17	3.825	34253.75	44174.75	14911.00	142.925	64.000	NA	NA
18	3.875	29070.75	53603.25	15165.00	179.575	61.500	NA	NA
19	3.525	26472.25	47203.25	18644.50	63.175	51.000	NA	NA
20	3.325	22976.25	49585.25	23179.50	93.875	80.000	NA	NA
21	3.225	28578.25	45362.25	19768.50	107.575	82.000	NA	NA
22	6.773	26675.58	39510.33	21129.85	86.542	100.685	NA	NA
23	34.462	26992.08	41921.63	23013.93	112.672	126.481	NA	NA
24	2.340	22026.83	49719.73	27082.70	131.732	137.510	NA	NA

NA: No analysis

TABLE AI-17: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF CREEPING BENTGRASS, VARIETY PENNCROSS, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	107.190	57.50
2	0	78.350	73.00
3	0	93.204	56.50
4	1	116.279	296.00
5	1	109.292	242.00
6	1	89.980	293.00
7	2	59.487	370.00
8	2	70.344	413.50
9	2	60.788	316.50
10	3	64.000	503.50
11	3	67.660	574.50
12	3	85.400	575.50
13	4	39.283	943.00
14	4	78.906	1092.00
15	4	84.690	1092.00
16	5	34.938	2312.50
17	5	48.513	2053.50
18	5	38.473	2473.50
19	6	2.450	6284.21
20	6	32.000	4228.68
21	6	36.308	3773.99

TABLE AI-18: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF CREEPING BENTGRASS, VARIETY PENNCROSS, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	15.00	37543.25	6929.75	4740.75	126.250	117.500	NA	NA
2	12.50	38468.75	6408.25	4648.75	97.750	215.000	NA	NA
3	11.50	39040.25	8046.25	4774.25	111.750	196.000	NA	NA
4	15.00	41722.75	6670.75	4583.75	118.250	134.000	NA	NA
5	15.00	39358.25	6490.25	4283.75	90.250	154.000	NA	NA
6	14.00	42534.75	7470.25	4464.75	98.250	233.000	NA	NA
7	18.00	37589.25	6219.75	4643.25	99.750	125.500	NA	NA
8	16.50	38707.75	7415.25	4842.75	138.750	282.000	NA	NA
9	14.50	41603.75	8558.75	4844.75	195.750	198.500	NA	NA
10	18.00	40119.75	7256.75	4713.75	127.750	125.000	NA	NA
11	18.50	36448.25	7543.25	5370.25	138.750	209.500	NA	NA
12	20.50	44709.75	7219.25	4801.75	151.750	357.500	NA	NA
13	22.0	41300.00	8068.00	6530.00	66.00	167.00	NA	NA
14	22.0	39929.00	7637.00	5491.00	75.00	303.00	NA	NA
15	18.50	40884.75	8856.75	6050.75	117.750	456.500	NA	NA
16	25.00	42933.75	7242.25	6668.25	65.750	218.000	NA	NA
17	19.50	36645.25	6775.75	5235.25	81.750	177.500	NA	NA
18	23.00	39713.75	6945.25	6087.75	108.250	493.500	NA	NA
19	39.47	33604.93	3940.46	5124.67	113.487	240.789	NA	NA
20	27.82	37618.65	3152.52	3896.79	107.768	263.646	NA	NA
21	37.43	42021.35	3540.67	4852.17	146.354	314.727	NA	NA

NA: No analysis

TABLE AI-19: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF, KENTUCKY BLUEGRASS, VARIETY BANJO, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	37.0864	52.15
2	0	49.7451	38.35
3	0	28.9778	88.22
4	1	54.3934	266.80
5	1	31.9831	250.30
6	1	44.5283	236.50
7	2	39.4615	373.15
8	2	36.1000	299.11
9	2	36.8478	404.03
10	3	39.5000	610.45
11	3	31.1455	591.05
12	3	26.8800	506.67
13	4	20.0172	805.25
14	4	16.0370	772.08
15	4	12.4200	1122.13
16	5	15.7288	2422.30
17	5	4.9130	7716.47
18	5	12.1800	2730.49
19	6	11.3333	17125.00
20	6	4.0000	8447.37
21	6	2.5385	8620.37

TABLE AI-20: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF KENTUCKY BLUEGRASS, VARIETY BANJO, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	11.4000	38725.50	4169.50	3897.50	100.300	80.50	37587.50	7637.50
2	8.8500	35332.50	4975.00	4703.50	130.050	117.00	36400.00	6637.50
3	10.5770	37728.02	4986.98	4594.54	108.662	125.98	40312.50	6712.50
4	12.1000	38250.50	4938.00	4710.50	116.450	104.00	40662.50	5812.50
5	11.3500	35672.50	5477.00	4732.00	115.400	233.50	39400.00	6475.00
6	14.5000	34121.50	5774.50	4851.50	111.050	106.50	41725.00	6012.50
7	13.8500	36279.50	5702.50	4848.00	112.350	210.50	42687.50	7275.00
8	11.3365	31838.63	5684.33	5078.44	130.904	230.72	39900.00	6937.50
9	13.5605	35046.79	5233.50	4383.29	122.758	175.10	28987.50	7162.50
10	16.8500	38055.50	5676.50	4874.00	117.950	147.50	43587.50	7837.50
11	12.7505	33686.87	8016.62	6271.17	149.484	185.32	40400.00	6312.50
12	16.2780	35976.11	5744.44	4912.78	115.834	123.33	30613.40	5897.33
13	15.5000	35905.00	6720.83	5800.83	63.083	432.50	41007.58	9290.87
14	15.1970	31502.12	6791.44	5938.03	55.439	163.79	34706.16	8211.48
15	19.1250	29121.25	8810.00	8152.50	128.375	167.50	41165.20	12763.20
16	14.6000	33240.00	8898.00	7501.00	60.600	313.00	20510.74	7061.07
17	2.9410	43555.88	20400.00	26891.18	312.353	1094.12	NA	NA
18	16.3935	40551.58	10447.56	9035.80	71.494	216.14	11663.27	4667.02
19	80.3570	41544.64	19857.14	11955.36	401.786	1357.14	NA	NA
20	2.6320	35750.00	14368.42	13065.79	236.842	815.79	NA	NA
21	<2.0000	35268.52	9018.52	8027.78	205.556	314.82	NA	NA

NA: No analysis

TABLE AI-21: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF LETTUCE, VARIETY ICEBERG, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	2322.75	97.30
2	0	2196.25	89.60
3	0	2226.75	88.20
4	1	2215.75	123.30
5	1	1917.50	120.50
6	1	2123.00	168.65
7	2	2111.00	177.60
8	2	2090.00	169.85
9	2	2031.75	159.60
10	3	1826.00	261.80
11	3	1980.75	237.97
12	3	2155.75	289.38
13	4	2141.00	357.00
14	4	1868.40	351.00
15	4	1783.25	382.36
16	5	1707.50	395.36
17	5	1515.00	425.85
18	5	1750.50	433.23
19	6	897.89	582.75
20	6	746.00	585.90
21	6	927.50	589.70
22	7	17.87	840.59
23	7	67.09	759.67
24	7	122.53	1001.87

TABLE AI-22: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF LETTUCE, VARIETY ICEBERG, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	1.00	42612.50	9080.00	7450.00	94.100	75.500	NA	NA
2	<1.00	38212.50	8500.00	6800.00	94.400	106.000	NA	NA
3	3.50	47362.50	9500.00	7400.00	94.200	71.000	NA	NA
4	1.50	49062.50	9000.00	6850.00	94.700	80.500	NA	NA
5	1.00	43312.50	8650.00	6650.00	111.400	72.000	NA	NA
6	4.50	52612.50	9850.00	7500.00	103.800	87.500	NA	NA
7	2.50	54112.50	9500.00	7300.00	103.400	91.000	NA	NA
8	1.50	48162.50	8800.00	7350.00	97.950	82.000	NA	NA
9	3.50	56812.50	9800.00	7300.00	93.800	86.500	NA	NA
10	3.80	57762.50	9000.00	6600.00	78.150	91.000	NA	NA
11	4.00	50212.50	8300.00	6650.00	83.650	76.000	NA	NA
12	4.50	58362.50	10450.00	7650.00	97.700	87.000	NA	NA
13	2.00	58063.00	8900.00	5900.00	99.00	62.00	NA	NA
14	4.00	61113.00	9750.00	6350.00	102.00	66.00	NA	NA
15	6.50	64562.50	11000.00	6750.00	98.800	86.500	NA	NA
16	2.50	72262.50	10100.00	5250.00	90.600	77.500	NA	NA
17	<1.00	74962.50	10200.00	5250.00	93.450	71.500	NA	NA
18	5.00	77912.50	10950.00	5250.00	88.700	64.500	NA	NA
19	<1.00	74112.50	10800.00	4550.00	98.050	68.000	NA	NA
20	1.15	84512.50	12650.00	5450.00	87.850	53.500	NA	NA
21	3.00	85512.50	13100.00	5550.00	96.400	76.000	NA	NA
22	<1.00	57037.50	9000.00	4650.00	71.250	133.500	NA	NA
23	3.08	73020.83	9916.67	4583.33	193.334	84.167	NA	NA
24	<1.00	108000.00	13933.33	5883.33	122.867	124.500	NA	NA

NA: No analysis

TABLE AI-23: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF LETTUCE, VARIETY BLACK SEEDED SIMPSON, PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1998

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	83.000	38.18
2	0	154.500	45.48
3	0	114.000	37.83
4	1	67.000	169.73
5	1	82.647	182.53
6	1	119.667	160.98
7	2	111.667	201.63
8	2	135.643	236.88
9	2	73.474	242.98
10	3	61.133	450.88
11	3	63.600	526.28
12	3	49.056	470.38
13	4	34.900	664.44
14	4	36.286	610.25
15	4	37.625	539.28
16	5	19.000	1100.08
17	5	22.800	1274.09
18	5	21.867	1070.12
19	6	5.643	1424.90
20	6	3.389	1589.76
21	6	5.938	1348.94

TABLE AI-24: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF LETTUCE, VARIETY BLACK SEEDED SIMPSON, PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1998

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	5.500	123395.00	15072.50	7097.50	119.900	173.500	NA	NA
2	5.800	133045.00	15972.00	7314.00	126.150	271.500	NA	NA
3	8.050	111595.00	13989.00	6172.50	96.950	64.000	NA	NA
4	5.100	125245.00	14473.00	6623.50	69.750	100.500	NA	NA
5	6.150	127595.00	14291.00	6561.00	81.400	111.000	NA	NA
6	6.400	131445.00	14529.00	6356.50	57.300	247.500	NA	NA
7	9.650	133345.00	14708.50	6126.00	47.200	176.000	NA	NA
8	6.400	147895.00	15864.50	6768.50	52.050	200.000	NA	NA
9	7.150	135395.00	12991.00	6547.00	68.700	162.500	NA	NA
10	6.750	129695.00	16734.00	6440.00	76.400	102.500	NA	NA
11	7.150	124895.00	17667.00	7139.00	92.300	212.500	NA	NA
12	6.350	117295.00	15757.00	6102.00	70.900	188.500	NA	NA
13	5.623	90283.65	18457.54	7368.24	79.053	170.359	NA	NA
14	6.102	81993.95	19315.94	8064.26	85.983	123.712	NA	NA
15	9.350	114095.00	18542.00	6643.00	60.500	128.500	NA	NA
16	4.649	81187.41	21371.01	10526.94	86.314	168.097	NA	NA
17	6.098	80808.34	21256.60	10748.68	126.399	501.320	NA	NA
18	9.986	84777.31	21428.07	10844.82	88.370	152.881	NA	NA
19	5.357	40718.25	13805.56	7865.08	72.619	315.476	NA	NA
20	4.603	57324.91	17702.17	10971.12	93.141	284.296	NA	NA
21	<2.000	51199.35	16222.22	9173.20	73.203	439.542	NA	NA

NA: No analysis

TABLE AI-25: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF LETTUCE, VARIETY BLACK SEEDED SIMPSON, PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1999

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	1176.67	109.45
2	0	1421.67	96.65
3	0	1333.33	116.80
4	1	1508.33	108.50
5	1	1511.67	105.45
6	1	1095.00	107.40
7	2	1325.00	148.75
8	2	1483.33	144.80
9	2	1181.67	201.55
10	3	1493.33	230.75
11	3	1573.33	225.50
12	3	1301.67	211.55
13	4	905.71	306.00
14	4	1138.33	320.00
15	4	764.29	336.55
16	5	908.57	422.95
17	5	1180.00	472.65
18	5	750.00	434.10
19	6	398.00	653.40
20	6	356.92	719.70
21	6	279.09	673.10
22	7	19.33	1160.25
23	7	24.12	1035.00
24	7	35.71	1194.00

TABLE AI-26: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF LETTUCE, VARIETY BLACK SEEDED SIMPSON, PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1999

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	7.60	60137.50	9945.0	6750.0	74.45	67.5	NA	NA
2	6.00	57887.50	11245.0	7100.0	76.00	83.5	NA	NA
3	7.00	70737.50	12295.0	8050.0	85.80	76.0	NA	NA
4	6.00	63937.50	10395.0	6100.0	104.50	68.0	NA	NA
5	4.80	62037.50	11045.0	6150.0	74.10	81.5	NA	NA
6	6.50	69787.50	11245.0	6500.0	74.80	89.0	NA	NA
7	6.10	70337.50	10345.0	6450.0	65.95	74.5	NA	NA
8	7.50	65187.50	10595.0	6450.0	60.10	71.5	NA	NA
9	6.00	74787.50	11495.0	6700.0	68.35	75.5	NA	NA
10	5.00	71387.50	10295.0	6100.0	67.10	59.5	NA	NA
11	5.25	68737.50	10595.0	5900.0	64.95	84.5	NA	NA
12	6.05	68387.50	10745.0	5900.0	58.65	59.5	NA	NA
13	6.00	77838.00	11545.0	6150.0	74.00	74.0	NA	NA
14	6.60	73638.00	11445.0	5550.0	75.00	115.0	NA	NA
15	5.50	74887.50	11545.0	5500.0	58.80	87.5	NA	NA
16	6.00	90387.50	12745.0	5250.0	72.90	89.0	NA	NA
17	8.00	89687.50	12545.0	5650.0	70.45	81.5	NA	NA
18	5.50	93437.50	14245.0	5600.0	67.00	88.0	NA	NA
19	6.50	92287.50	13745.0	5250.0	71.05	81.5	NA	NA
20	5.90	95387.50	14295.0	5550.0	86.00	69.5	NA	NA
21	5.60	93837.50	14645.0	5600.0	79.25	66.0	NA	NA
22	7.50	58462.50	15435.0	7350.0	96.45	153.0	NA	NA
23	8.25	44062.50	10935.0	4950.0	69.00	146.0	NA	NA
24	4.50	55462.50	11835.0	5400.0	50.70	60.5	NA	NA

NA: No analysis

TABLE AI-27: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF OAT PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	158.480	50.55
2	0	168.542	54.05
3	0	217.619	53.35
4	1	165.708	273.45
5	1	207.880	269.90
6	1	177.360	287.75
7	2	262.783	506.40
8	2	157.556	485.55
9	2	170.727	507.65
10	3	205.640	970.70
11	3	204.091	1004.40
12	3	149.762	989.30
13	4	65.304	5188.00
14	4	91.783	4401.00
15	4	69.826	4872.70
16	5	31.920	13460.00
17	5	33.000	13960.00
18	5	26.682	17940.00
19	6	17.905	20373.33
20	6	26.350	15030.12
21	6	16.476	27403.56

TABLE AI-28: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF OAT PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	5.40	54967.50	6630.50	4957.50	80.500	176.500	NA	NA
2	6.75	51097.50	6500.50	5109.00	108.000	117.500	NA	NA
3	4.70	55363.50	6848.50	5199.50	93.600	100.000	NA	NA
4	7.00	59080.50	7722.50	5400.50	110.000	175.000	NA	NA
5	6.00	50852.50	6750.50	4987.50	112.050	84.000	NA	NA
6	5.75	56065.00	8197.00	5612.50	130.400	135.500	NA	NA
7	6.50	53348.50	7191.00	5248.00	108.900	165.000	NA	NA
8	7.00	49039.50	7523.00	5477.50	101.500	78.500	NA	NA
9	5.80	56611.50	8939.50	6549.50	109.100	220.500	NA	NA
10	6.85	51040.00	9113.50	6270.00	154.800	169.000	NA	NA
11	6.70	50172.00	9908.00	6836.50	154.200	142.000	NA	NA
12	7.35	56154.50	11285.00	7517.00	166.550	211.000	NA	NA
13	7.00	33732.00	12430.00	9619.00	127.00	119.00	NA	NA
14	6.00	31056.00	14238.00	9759.00	133.00	169.00	NA	NA
15	5.30	26721.50	16565.50	11664.00	163.600	166.500	NA	NA
16	8.40	26425.50	13752.00	11114.50	637.700	146.000	NA	NA
17	8.70	20751.50	15433.00	12300.50	695.200	77.000	NA	NA
18	7.40	19425.50	17351.00	14761.50	310.000	221.000	NA	NA
19	10.27	21068.67	16368.00	11279.33	805.467	109.333	NA	NA
20	9.04	24432.23	15514.06	10583.84	731.426	269.076	NA	NA
21	8.46	18994.81	18820.48	13588.28	946.884	375.371	NA	NA

NA: No analysis

TABLE AI-29: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF PERENNIAL RYEGRASS, VARIETY ESSENCE, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	23.4808	145.38
2	0	28.5227	50.78
3	0	25.4655	57.73
4	1	29.6667	687.73
5	1	25.3600	604.28
6	1	33.7400	620.98
7	2	26.7660	1213.93
8	2	21.4182	1181.68
9	2	20.4583	1156.99
10	3	9.7273	2844.67
11	3	9.7255	1910.39
12	3	13.8605	2065.05
13	4	5.4043	7606.89
14	4	4.7907	6524.43
15	4	6.9577	6400.55
16	5	2.0244	14899.70
17	5	2.1538	10573.68
18	5	2.3167	9188.94
19	6	2.5714	19527.28
20	6	2.1887	13308.38
21	6	2.8182	8568.89
22	7	5.3404	5575.43
23	7	4.4348	6373.55
24	7	4.6047	4796.21

TABLE AI-30: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF PERENNIAL RYEGRASS, VARIETY ESSENCE, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	12.2000	61671.25	9690.25	6720.00	102.175	303.250	NA	NA
2	13.3000	63839.25	8711.25	5961.50	112.625	144.250	NA	NA
3	9.9500	61788.75	8072.25	5769.00	106.625	151.750	NA	NA
4	14.3500	62278.75	8394.25	6465.50	132.475	147.750	NA	NA
5	13.1500	65988.25	8428.75	6036.50	128.575	177.250	NA	NA
6	13.8500	63529.75	8304.25	6139.50	133.625	159.250	NA	NA
7	17.2000	65152.25	9637.25	7022.00	143.825	213.750	NA	NA
8	14.8500	67660.25	8651.75	6822.50	143.125	148.250	NA	NA
9	15.8375	63197.52	10378.38	7625.67	147.798	212.186	NA	NA
10	16.9375	71799.57	18415.67	16349.32	98.108	308.336	NA	NA
11	16.2225	62098.33	12229.44	10148.89	87.500	119.445	NA	NA
12	14.2000	65388.50	11739.50	9530.00	91.250	156.500	NA	NA
13	16.6655	44187.58	17854.50	10192.47	135.008	277.159	NA	NA
14	12.4410	46489.85	14069.56	7858.24	127.544	223.676	NA	NA
15	19.0465	70668.12	15622.05	9777.21	175.419	314.621	NA	NA
16	10.9320	37791.10	7544.49	5440.68	151.907	146.186	NA	NA
17	7.9410	40620.88	6648.53	3854.12	179.912	161.471	NA	NA
18	11.3750	42543.13	6636.88	3950.00	153.938	249.375	NA	NA
19	22.3130	31650.94	11807.81	7233.75	248.906	134.063	NA	NA
20	9.7250	33211.81	10064.01	5245.06	198.379	124.451	NA	NA
21	8.0660	35211.09	7337.97	4282.08	200.590	106.840	NA	NA
22	10.5000	47453.25	6926.25	4291.50	92.475	110.250	NA	NA
23	12.7000	46148.50	7761.50	4388.00	125.550	137.500	NA	NA
24	11.5060	45167.47	6768.32	3848.86	123.366	139.347	NA	NA

NA: No analysis

TABLE AI-31: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF RED TOP, VARIETY STREAKER, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	43.3750	73.75
2	0	69.5102	73.50
3	0	93.4419	68.00
4	1	62.0545	372.30
5	1	55.1087	468.95
6	1	60.2609	473.80
7	2	58.0714	668.10
8	2	34.9048	609.85
9	2	56.9000	751.45
10	3	25.8718	824.42
11	3	20.2745	827.00
12	3	30.7391	876.42
13	4	17.6410	2782.88
14	4	14.9688	3005.50
15	4	12.1489	2825.70

TABLE AI-32: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF RED TOP, VARIETY STREAKER, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	15.0625	41465.94	9355.94	5498.75	161.001	115.000	NA	NA
2	12.1000	51056.25	9123.75	5936.00	171.850	150.000	NA	NA
3	14.5500	49578.25	9379.75	5673.00	171.400	185.500	NA	NA
4	12.6500	44358.25	7742.25	5086.50	116.850	110.000	NA	NA
5	13.0000	51149.25	7434.75	5355.50	163.400	288.000	NA	NA
6	15.7000	49732.75	9712.25	5716.00	138.750	217.000	NA	NA
7	17.1500	46674.75	8699.75	5559.50	108.850	219.000	NA	NA
8	14.6000	48788.25	8625.25	6317.50	133.850	134.000	NA	NA
9	16.0000	45726.75	8883.75	5853.00	129.550	204.000	NA	NA
10	19.0835	43513.75	9570.42	7674.17	83.167	209.167	NA	NA
11	16.3750	42139.38	8278.13	6647.50	74.000	102.500	NA	NA
12	17.0835	46272.08	8438.75	6385.83	87.417	161.667	NA	NA
13	18.5000	37308.13	8194.38	5825.00	91.875	113.750	NA	NA
14	20.5000	42906.88	7208.13	6701.25	99.750	138.750	NA	NA
15	14.8000	35506.50	8807.50	6594.00	103.900	145.000	NA	NA

NA: No analysis

TABLE AI-33: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF REED CANARY GRASS PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	135.960	49.30
2	0	87.133	43.60
3	0	91.696	42.60
4	1	164.360	649.00
5	1	107.636	568.30
6	1	149.571	587.85
7	2	124.051	1190.65
8	2	112.351	1382.45
9	2	157.690	1373.95
10	3	82.958	1956.30
11	3	53.882	1837.20
12	3	82.868	1539.60
13	4	19.462	5328.31
14	4	19.667	5370.94
15	4	43.679	3627.83
16	5	4.167	13184.35
17	5	5.556	14477.44
18	5	6.000	7257.27
19	6	1.800	17200.00
20	6	3.333	26505.00

TABLE AI-34: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF REED CANARY GRASS PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	10.625	51141.50	5991.25	4932.50	74.75	142.00	NA	NA
2	13.725	52343.00	6782.75	5302.50	76.65	157.50	NA	NA
3	14.525	52843.00	7403.75	5268.00	99.65	183.00	NA	NA
4	11.025	53501.50	7399.25	4552.00	146.15	105.50	NA	NA
5	11.675	57632.00	7119.75	4542.50	144.25	106.50	NA	NA
6	11.575	54016.00	7787.75	5044.00	154.50	151.00	NA	NA
7	11.175	49878.50	11426.25	6158.50	191.05	116.50	NA	NA
8	13.675	49784.50	9708.25	6113.50	216.10	105.00	NA	NA
9	12.875	51169.50	9175.25	5393.50	178.60	132.50	NA	NA
10	11.925	54555.50	12983.75	7382.50	152.00	94.00	NA	NA
11	9.925	51863.00	13099.75	7465.50	140.95	88.50	NA	NA
12	11.925	52087.50	11158.75	6309.50	173.30	100.50	NA	NA
13	10.297	56183.05	14140.25	10660.17	190.00	75.42	NA	NA
14	10.206	57162.35	13952.06	9695.29	149.00	77.94	NA	NA
15	11.750	59915.56	10220.83	6122.78	123.78	84.44	NA	NA
16	11.576	51554.35	18624.46	7542.39	662.61	257.61	NA	NA
17	10.291	57606.98	12709.88	7929.07	694.88	289.54	NA	NA
18	15.682	55663.64	12211.36	5168.18	480.00	340.91	NA	NA
19	39.167	61533.33	10025.00	6750.00	820.00	1316.67	NA	NA
20	58.750	47850.00	13287.50	9875.00	1230.00	225.00	NA	NA

NA: No analysis

TABLE AI-35: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF SPINACH PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	260.000	100.20
2	0	159.750	106.30
3	0	249.375	123.60
4	1	210.500	496.15
5	1	235.750	442.85
6	1	290.875	524.20
7	2	168.750	743.75
8	2	161.250	728.20
9	2	206.875	779.15
10	3	79.250	1132.28
11	3	56.875	1480.23
12	3	112.000	1125.80
13	4	87.375	1191.00
14	4	85.375	942.60
15	4	88.500	1197.70
16	5	32.200	1792.11
17	5	19.381	1851.11
18	5	18.364	1821.17
19	6	7.895	3639.27
20	6	14.200	2558.50
21	6	11.000	2473.88
22	7	9.818	4275.09
23	7	8.696	4363.89
24	7	12.286	4948.97

TABLE AI-36: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF SPINACH PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	8.1500	95587.00	12549.00	19834.00	129.300	233.500	63150.00	7872.50
2	9.0000	95492.00	12946.00	19727.50	117.250	198.500	74039.54	3227.77
3	8.0500	95458.50	15513.00	21019.00	198.900	271.500	68588.68	7632.50
4	7.1500	95457.50	13099.00	21205.00	79.900	230.000	69025.00	8309.47
5	7.6500	95498.50	12708.50	19199.00	73.950	182.500	60562.50	8168.75
6	8.0000	95483.50	12308.50	19254.50	94.100	139.000	66445.08	7477.50
7	6.0000	91589.00	13293.00	22030.50	112.400	171.000	68616.16	7186.07
8	6.9500	87931.50	14297.50	21891.50	105.300	151.000	67043.44	9359.54
9	5.9500	90420.50	14294.00	23382.00	126.550	141.500	59370.98	7994.56
10	4.0390	82990.70	26187.00	19720.35	161.613	182.044	61231.16	7730.34
11	3.5820	74183.88	56918.00	29275.00	297.220	265.043	63329.97	4793.05
12	1.7000	79086.00	30503.00	20748.00	200.800	120.000	65866.43	7449.45
13	2.9000	87291.00	25623.00	19582.00	115.100	158.000	60987.71	7078.13
14	7.1000	91992.00	20147.00	19512.00	76.300	197.000	76635.17	7656.81
15	4.0000	82765.00	27777.00	21430.00	131.400	168.000	47542.52	8198.20
16	4.4570	43681.71	49599.43	21250.29	112.200	361.715	NA	7661.82
17	2.8570	49741.71	47696.50	21528.14	98.472	382.143	NA	6512.10
18	6.7285	41662.86	46376.93	20413.57	141.700	270.000	NA	3815.41
19	7.9090	29031.82	25965.00	15916.36	34.364	441.818	NA	NA
20	3.2500	35137.50	27843.75	14440.00	30.750	415.000	NA	8604.55
21	6.1880	27240.00	26192.81	15181.88	22.500	275.625	NA	6829.18
22	6.6860	38568.00	24081.43	18764.57	64.286	306.857	NA	NA
23	7.2220	32259.26	29925.00	17707.41	67.963	551.852	NA	NA
24	4.6290	34834.29	32791.71	19464.00	82.629	449.143	NA	NA

NA: No analysis

TABLE AI-37: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF TALL FESCUE, VARIETY HOUNDOG, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	26.7805	81.88
2	0	27.5000	87.66
3	0	26.4706	101.38
4	1	20.8043	583.96
5	1	21.6667	595.44
6	1	27.1707	612.63
7	2	19.2951	838.03
8	2	20.8214	918.71
9	2	26.6364	981.71
10	3	17.4250	1363.21
11	3	18.5333	1298.21
12	3	20.0250	1261.21
13	4	12.3704	2281.06
14	4	13.6296	2236.44
15	4	17.3824	2446.88
16	5	1.8333	14916.63
17	5	1.7600	13808.75
18	5	1.2105	14779.18
19	6	2.3333	14188.31
20	6	1.2308	32689.97
21	6	2.2667	14409.94
22	7	1.9737	12975.38
23	7	1.8438	12212.53
24	7	1.3333	9710.65

TABLE AI-38: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF TALL FESCUE, VARIETY HOUNDOG, PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	11.2915	58403.33	6850.00	7654.58	73.333	105.834	NA	NA
2	8.7190	51778.75	7958.75	7660.31	70.375	116.250	NA	NA
3	8.8750	54417.50	8265.00	8131.25	77.333	123.334	NA	NA
4	9.7920	56430.83	6150.83	7149.58	100.500	115.000	NA	NA
5	6.5620	63113.53	7554.42	9149.06	77.038	100.299	NA	NA
6	11.9585	57109.17	7223.33	7782.92	80.417	100.834	NA	NA
7	10.8750	57839.00	6736.00	7211.25	88.500	111.000	NA	NA
8	11.4580	57151.67	9318.33	9100.42	85.167	113.333	NA	NA
9	10.1250	62548.33	7323.33	7337.08	74.667	125.000	NA	NA
10	12.4580	59028.33	8538.33	8382.08	46.500	113.333	NA	NA
11	13.1250	54816.67	8791.67	7992.08	51.167	90.000	NA	NA
12	14.7920	55365.00	8050.00	8362.08	62.167	90.000	NA	NA
13	10.9380	50182.50	9555.00	8118.13	27.000	157.500	NA	NA
14	7.7810	43950.68	10438.78	7502.13	23.299	90.136	NA	NA
15	21.4580	47530.00	10038.33	8132.08	24.333	130.000	NA	NA
16	21.9770	33837.21	9502.33	7426.74	185.581	432.558	NA	NA
17	19.6370	38347.00	7930.60	8567.04	181.703	246.057	NA	NA
18	9.0560	33185.76	5888.55	6606.04	176.471	297.214	NA	NA
19	14.6700	34449.48	10103.63	7842.94	160.881	217.617	NA	NA
20	5.8100	22605.63	7035.21	13294.01	411.972	633.803	NA	NA
21	18.4600	32246.13	8901.89	7756.89	170.912	320.138	NA	NA
22	9.5340	32191.53	8461.02	7425.00	127.119	188.136	NA	NA
23	19.3200	27462.48	6858.01	6366.63	121.704	267.748	NA	NA
24	7.2120	28714.29	5357.14	5557.01	112.088	313.187	NA	NA

NA: No analysis

TABLE AI-39: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF TOMATO PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1998

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	2153.80	61.38
2	0	2944.50	64.08
3	0	3300.00	45.43
4	1	2128.75	109.08
5	1	2655.00	151.13
6	1	1708.60	124.63
7	2	2389.00	147.18
8	2	2877.50	145.23
9	2	3333.75	137.48
10	3	2283.80	184.13
11	3	3394.25	194.38
12	3	4363.33	184.88
13	4	4950.00	280.03
14	4	109.50	972.21
15	4	3726.33	226.98
16	5	595.00	479.88
17	5	2281.25	483.68
18	5	3869.50	364.38
19	6	366.67	1155.79
20	6	973.33	912.63
21	6	75.00	1008.35
22	7	70.00	1563.27

TABLE AI-40: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF TOMATO PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1998

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	8.950	36860.50	33029.50	15347.50	88.400	76.500	43087.5	2995.0
2	8.500	36399.50	32500.00	15035.50	99.600	73.500	40837.5	2527.5
3	6.450	37118.50	30284.00	13677.50	71.700	88.000	39537.5	2800.0
4	12.400	34518.50	34560.00	16120.00	101.800	75.500	44212.5	3140.0
5	11.300	39764.50	33078.50	16903.00	138.900	83.000	43825.0	3095.0
6	10.500	37956.50	32995.00	16478.00	123.600	76.000	43275.0	2780.0
7	11.650	38308.50	31371.00	16239.00	107.600	77.500	42062.5	2780.0
8	11.300	35296.50	32373.50	15991.00	109.900	75.500	42125.0	2702.5
9	11.000	36615.00	30279.50	15783.00	100.200	81.500	42712.5	2720.0
10	11.550	37905.00	30821.50	15561.00	94.700	81.500	44312.5	2915.0
11	10.950	39106.50	30451.50	16508.00	126.150	102.000	44875.0	2892.5
12	13.350	36646.00	31779.00	15190.50	122.100	111.500	42962.5	2982.5
13	12.700	45226.50	32880.50	15152.50	87.500	65.000	44087.5	2965.0
14	13.822	18947.12	39558.38	25896.60	261.361	92.670	NA	NA
15	12.900	40223.00	34480.00	15204.50	90.650	82.500	45312.5	3090.0
16	16.775	41239.50	35230.88	16722.88	103.975	69.750	52387.5	7115.0
17	16.800	36350.00	34727.50	17606.50	109.700	63.000	49162.5	3970.0
18	14.500	45975.00	28936.50	14521.50	80.350	64.000	47762.5	4177.5
19	16.667	35331.67	44800.83	23497.50	152.833	65.000	43087.5	3680.0
20	18.650	28534.50	41117.00	19648.00	125.450	61.000	45087.5	3925.0
21	12.462	19947.69	47923.85	26919.23	208.615	50.769	NA	NA
22	17.419	16122.58	48520.16	23233.07	200.323	62.903	NA	NA

NA: No analysis

TABLE AI-41: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF TOMATO PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1999

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	3222.00	103.60
2	0	3366.00	101.45
3	0	2910.00	102.30
4	1	3024.00	127.25
5	1	2898.00	147.90
6	1	3160.00	151.70
7	2	3276.00	177.05
8	2	2698.33	185.15
9	2	2826.00	175.10
10	3	3242.00	241.25
11	3	3226.00	261.30
12	3	3525.00	265.40
13	4	3210.00	283.85
14	4	3122.00	339.35
15	4	3476.00	284.35
16	5	2716.67	405.50
17	5	2952.00	424.75
18	5	2942.00	399.50
19	6	1231.25	564.65
20	6	1354.00	505.00
21	6	802.22	610.90

TABLE AI-42: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF TOMATO PLANTED IN SOIL SPIKED WITH $ZnSO_4$ IN 1999

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	7.40	42400	27700	14400	84.45	69.5	NA	NA
2	8.00	45800	24650	13600	72.05	68.0	NA	NA
3	7.35	44300	28100	14400	88.65	71.0	NA	NA
4	8.30	45350	26500	13800	82.35	87.5	NA	NA
5	7.85	48550	25000	14500	93.80	65.0	NA	NA
6	7.15	43400	26300	14850	95.80	67.5	NA	NA
7	7.20	45700	24800	14450	75.60	61.0	NA	NA
8	7.95	50450	25850	15350	96.30	67.0	NA	NA
9	9.65	49200	30250	14650	76.60	81.0	NA	NA
10	8.45	38100	26350	15500	97.55	67.0	NA	NA
11	8.70	49650	23500	15300	95.60	60.0	NA	NA
12	8.40	48550	23150	13850	81.85	67.5	NA	NA
13	8.55	45600	22950	13650	72.80	59.5	NA	NA
14	9.05	54250	21400	14000	76.20	53.5	NA	NA
15	8.85	40500	24250	14200	76.65	58.0	NA	NA
16	9.45	44750	23300	14650	91.50	48.5	NA	NA
17	11.00	49000	24700	14950	93.45	52.0	NA	NA
18	11.00	45100	26500	15000	79.75	52.5	NA	NA
19	13.80	45000	29050	16150	92.20	70.0	NA	NA
20	10.25	52300	23600	14950	83.45	58.5	NA	NA
21	13.00	46350	28700	15750	100.85	115.0	NA	NA

NA: No analysis

TABLE AI-43: PLANT DRY MATTER PRODUCTION AND ZN CONCENTRATION IN LEAVES OF WHEAT PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Index of Dosage Level	Dry Matter (mg/plant)	Tissue Zn (mg/kg)
1	0	249.682	100.38
2	0	231.333	88.88
3	0	202.040	81.93
4	1	239.000	280.63
5	1	301.833	328.23
6	1	298.261	293.13
7	2	255.840	552.13
8	2	203.565	643.28
9	2	204.280	590.88
10	3	194.500	1146.48
11	3	249.591	1090.28
12	3	184.560	970.73
13	4	176.261	2315.93
14	4	188.542	1953.33
15	4	137.280	1763.48
16	5	73.591	5312.75
17	5	74.000	5304.86
18	5	32.250	8995.56
19	6	58.136	12671.64
20	6	54.783	11893.86
21	6	69.600	9449.48

TABLE AI-44: NUTRIENT ELEMENT CONCENTRATIONS IN LEAVES OF WHEAT PLANTED IN SOIL SPIKED WITH $ZnSO_4$

Pot #	Tissue Cu (mg/kg)	Tissue K (mg/kg)	Tissue Ca (mg/kg)	Tissue Mg (mg/kg)	Tissue Mn (mg/kg)	Tissue Fe (mg/kg)	Tissue N (mg/kg)	Tissue P (mg/kg)
1	12.3250	55214.00	6227.00	4097.50	127.950	514.500	NA	NA
2	8.7750	54894.50	4829.00	3157.00	90.600	83.500	NA	NA
3	8.5750	56631.00	4843.00	3595.50	122.000	92.500	NA	NA
4	9.9250	56225.50	5996.50	3785.00	166.250	109.000	NA	NA
5	9.5250	61565.50	5568.50	3593.00	175.200	169.000	NA	NA
6	9.2250	58564.50	5377.00	3715.50	178.700	85.000	NA	NA
7	8.2750	55861.50	6203.50	3877.00	177.400	123.000	NA	NA
8	8.2750	54577.50	6441.50	4052.50	169.750	100.500	NA	NA
9	7.5250	53656.00	6407.50	4164.00	177.350	78.000	NA	NA
10	8.8750	47611.00	8507.00	4857.50	119.900	141.500	NA	NA
11	7.4250	48665.50	7747.50	4718.00	140.900	85.000	NA	NA
12	7.1250	53123.50	6669.00	4483.50	113.050	62.500	NA	NA
13	5.8750	44593.00	9834.50	6360.50	145.400	108.500	NA	NA
14	7.7750	44328.50	7723.50	5379.00	141.250	95.000	NA	NA
15	5.8250	47100.50	7368.50	5119.00	143.850	79.000	NA	NA
16	7.1390	30025.56	6885.56	9146.67	534.778	74.445	NA	NA
17	6.8055	30218.89	8020.56	9258.33	535.834	53.334	NA	NA
18	6.9380	24027.50	4967.50	7480.00	433.375	106.250	NA	NA
19	7.6945	14148.61	3201.94	4026.39	406.834	115.000	NA	NA
20	7.6945	23098.33	6148.33	8361.11	335.945	59.445	NA	NA
21	7.3250	27512.00	5492.00	6211.50	309.650	46.000	NA	NA

NA: No analysis

APPENDIX II

RESULTS OF ADAPTIVE GROUPING ANALYSIS INCLUDING GROUPING INDEX, ESTIMATED GROUP MEAN PLANT DRY MATTER AND AVERAGE LEAF ZINC CONCENTRATION FOR EACH ZINC DOSAGE LEVEL

TABLE AII-1: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR 10 WEEK OLD BEET, VARIETY EARLY WONDER, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	3258	46.5
1	0	3258	188
2	0	3258	217
3	0	3258	504
4	0	3258	739
5	1	447.5	1761

TABLE AII-2: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR FOUR WEEK OLD BEET, VARIETY RED BALL, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	153.3	50.4
1	0	153.3	103
2	0	153.3	123
3	0	153.3	242
4	1	43.5	832
5	1	43.5	1483
6	1	43.5	5302

TABLE AII-3: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR 10 WEEK OLD BEET, VARIETY RED BALL, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	5529	47.2
1	0	5529	131
2	0	5529	170
3	0	5529	390
4	1	3288	653
5	2	205.5	1496

TABLE AII-4: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR FOUR WEEK OLD BEET, VARIETY RUBY QUEEN, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	165.7	65.1
1	0	165.7	97.0
2	0	165.7	148
3	0	165.7	230
4	1	31.1	586
5	1	31.1	1148
6	1	31.1	3293

TABLE AII-5: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR 10 WEEK OLD BEET, VARIETY RUBY QUEEN, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	2139	44.1
1	0	2139	190
2	0	2139	167
3	0	2139	347
4	0	2139	881
5	1	56.9	1762

TABLE AII-6: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR BUFFALO GRASS INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	589	76.3
1	0	589	498
2	0	589	1064
3	1	200.6	1589
4	2	20.1	4313

TABLE AII-7: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR CORN, VARIETY PIONEER 3394, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	2754	39.1
1	0	2754	111
2	1	3146	244
3	2	2212	635
4	3	909	1265
5	4	360	7283
6	4	360	12700

TABLE AII-8: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR COTTON, VARIETY ACALLA, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	1438	51.3
1	0	1438	61.7
2	0	1438	79.6
3	0	1438	142
4	0	1438	296
5	1	940	496
6	2	187.6	692
7	2	187.6	1091

TABLE AII-9: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR CREEPING BENTGRASS, VARIETY PENNCROSS, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	99.1	62.3
1	0	99.1	277
2	1	67.8	367
3	1	67.8	551
4	1	67.8	1036
5	2	40.6	2280
6	3	12.7	4762

TABLE AII-10: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR KENTUCKY BLUEGRASS, VARIETY BANJO, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	38.05	59.57
1	0	38.05	251.20
2	0	38.05	358.76
3	0	38.05	569.39
4	1	11.02	899.82
5	1	11.02	4289.75
6	1	11.02	11397.58

TABLE AII-11: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR LETTUCE, VARIETY ICEBERG, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	2249	91.7
1	1	2020	137
2	1	2020	169
3	1	2020	263
4	1	2020	363
5	2	1658	418
6	3	857	586
7	4	69.2	867

TABLE AII-12: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR OAT, VARIETY OGLE, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	187.2	52.7
1	0	187.2	277
2	0	187.2	500
3	0	187.2	988
4	1	75.6	4821
5	2	25.4	15120
6	2	25.4	20936

TABLE AII-13: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR PERENNIAL RYEGRASS, VARIETY ESSENCE, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	27.7	84.6
1	0	27.7	638
2	1	22.9	1184
3	2	11.1	2273
4	3	3.80	6844
5	3	3.80	11554
6	3	3.80	13802
7	3	3.80	5582

TABLE AII-14: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR REED CANARY GRASS INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	125.6	45.2
1	0	125.6	602
2	0	125.6	1316
3	1	73.2	1778
4	2	13.0	4776
5	2	13.0	11640
6	2	13.0	21853

TABLE AII-15: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR SPINACH, VARIETY BLOOMSDALE LONGSTANDING, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	215.9	110
1	0	215.9	488
2	0	215.9	750
3	1	84.9	1246
4	1	84.9	1110
5	2	14.9	1821
6	2	14.9	2891
7	2	14.9	4529

TABLE AII-16: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR TALL FESCUE, VARIETY HOUNDOG, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg $plant^{-1}$)	Average Tissue Zinc (mg kg^{-1})
0	0	24.1	90.3
1	0	24.1	597
2	0	24.1	913
3	1	18.7	1308
4	2	14.5	2321
5	3	1.75	14502
6	3	1.75	20429
7	3	1.75	11633

TABLE AII-17: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR TOMATO, VARIETY RUTGERS, GROWN IN 1999 INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	3042	102
1	0	3042	142
2	0	3042	179
3	1	3300	256
4	1	3300	303
5	2	2870	410
6	3	1129	560

TABLE AII-18: RESULTS OF ADAPTIVE GROUPING ANALYSIS FOR WHEAT, VARIETY MADISON, INCLUDING GROUPING DESIGNATION (GROUP INDEX), ESTIMATED GROUP MEAN DRY MATTER AND MEAN LEAF ZINC CONCENTRATION FOR EACH DOSAGE LEVEL

Index of Dosage Level	Group Index	Estimated Group Mean Dry Matter (mg plant^{-1})	Average Tissue Zinc (mg kg^{-1})
0	0	253.7	90.4
1	0	253.7	301
2	1	215.4	595
3	1	215.4	1069
4	2	167.4	2011
5	3	60.4	6538
6	3	60.4	11338

APPENDIX III

OBSERVED AND INITIALLY CONSTANT SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR GRASSES AND FOOD AND FIBER CROPS

FIGURE AIII-1: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BEET, VARIETY EARLY WONDER, 10 WEEKS AFTER PLANTING

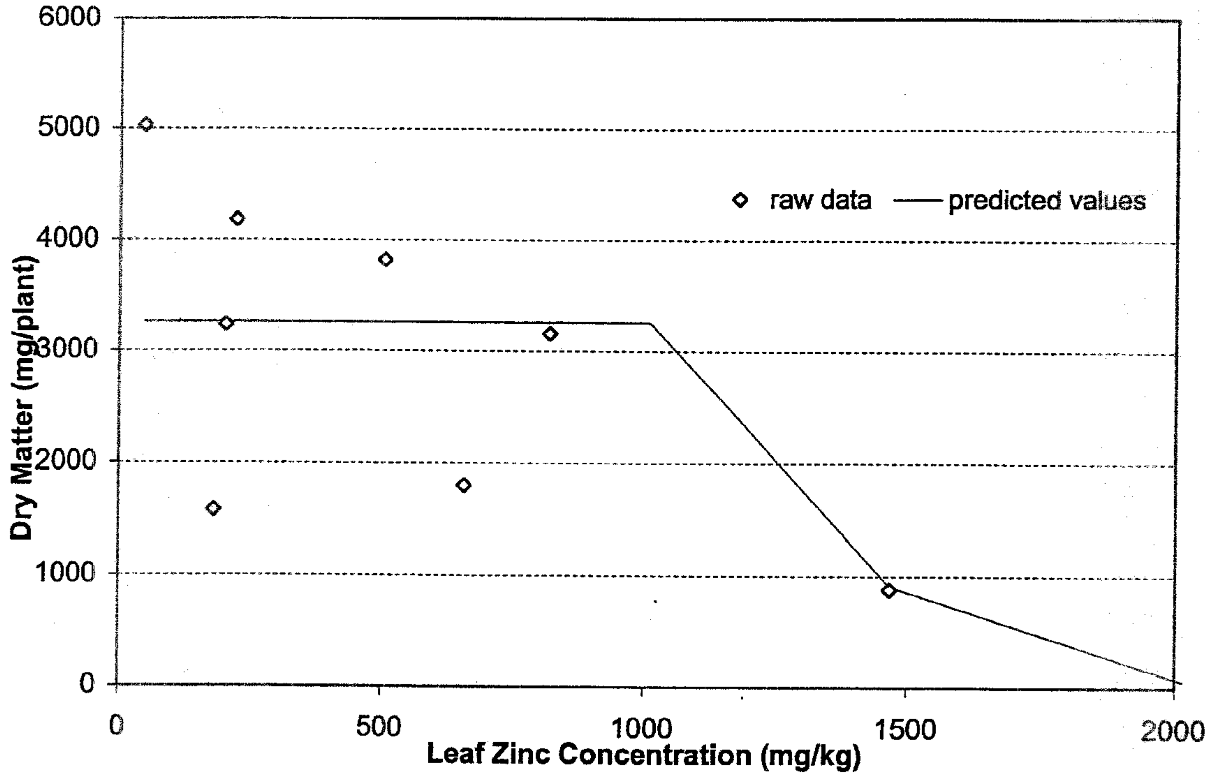

FIGURE AIII-2: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BEET, VARIETY RED BALL, FOUR WEEKS AFTER PLANTING

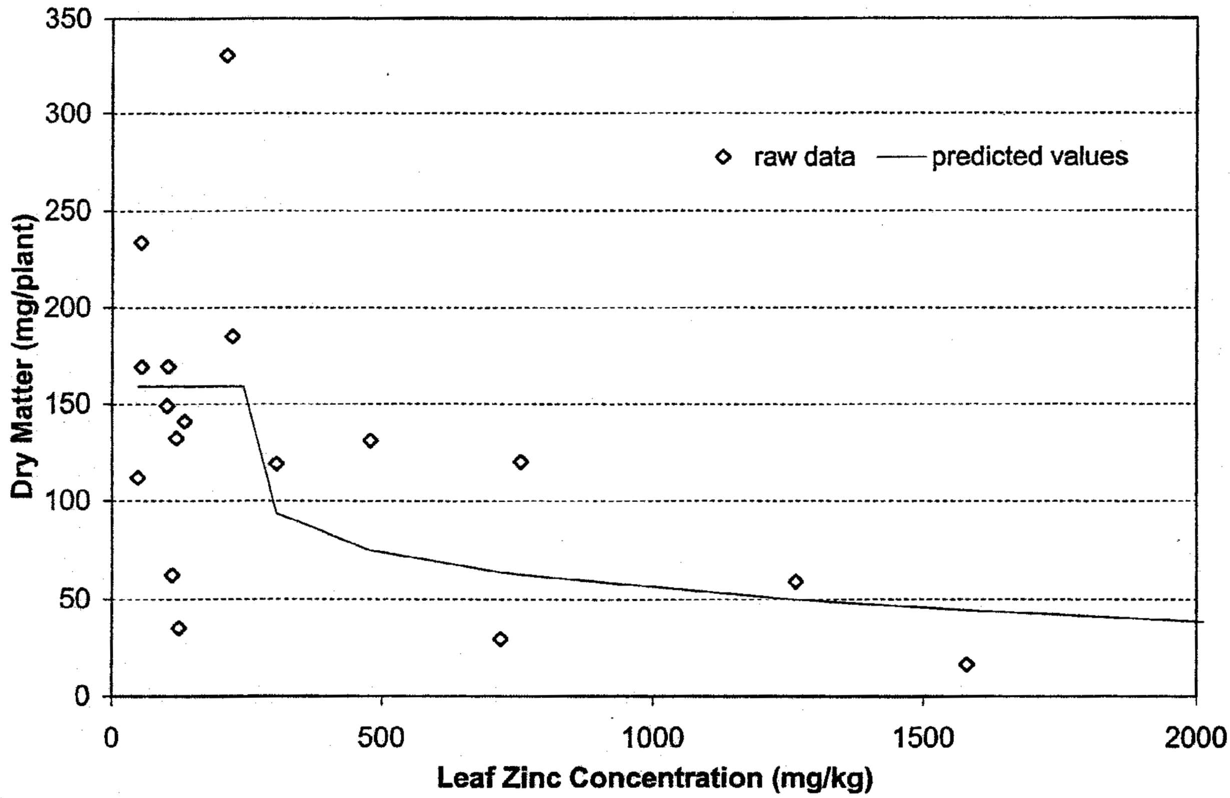

FIGURE AIII-3: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BEET, VARIETY RED BALL, 10 WEEKS AFTER PLANTING

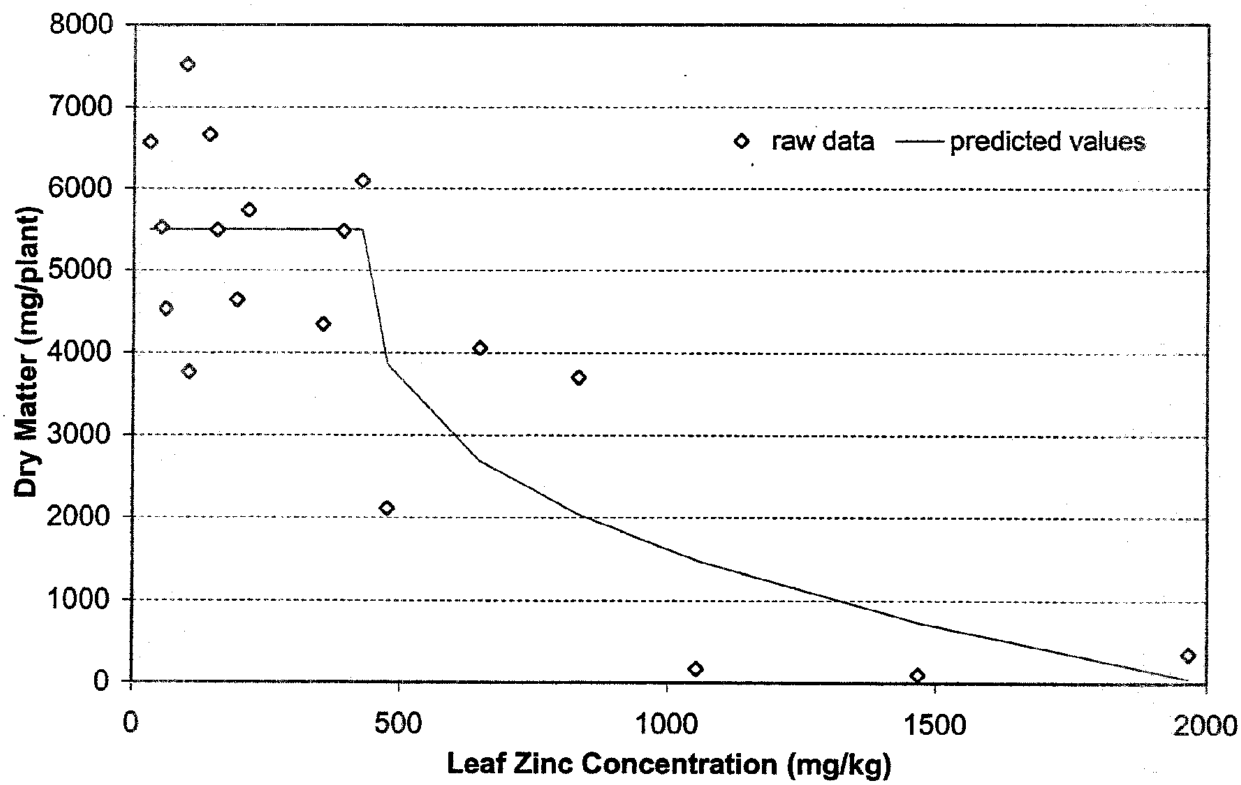

FIGURE AIII-4: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BEET, VARIETY RUBY QUEEN, FOUR WEEKS AFTER PLANTING

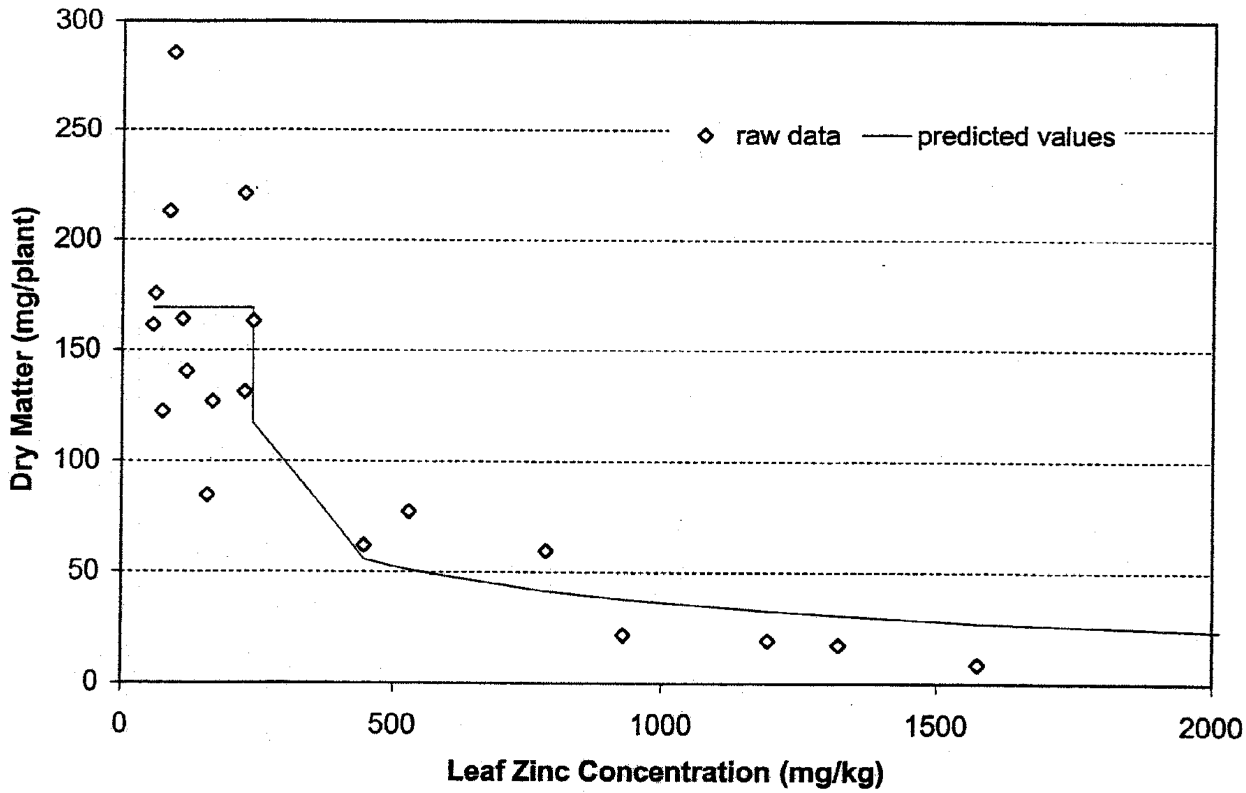

FIGURE AIII-5: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BEET, VARIETY RUBY QUEEN, 10 WEEKS AFTER PLANTING

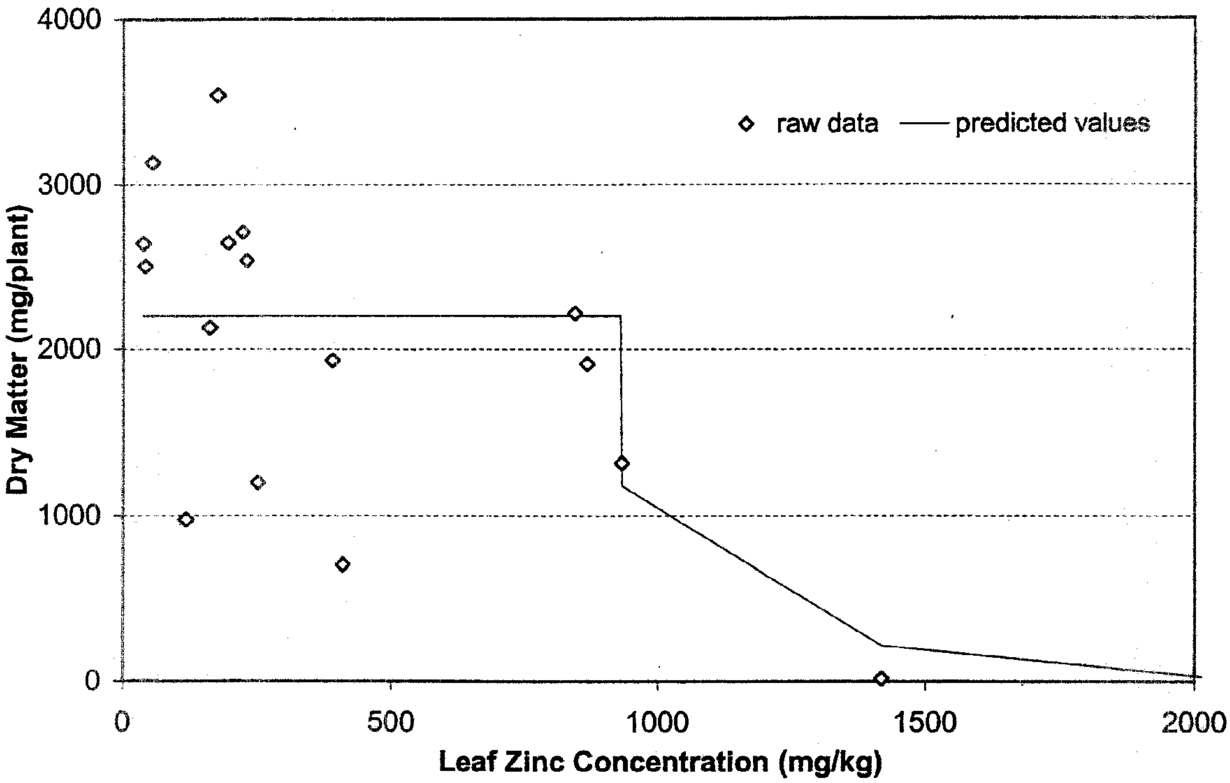

FIGURE AIII-6: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR BUFFALO GRASS

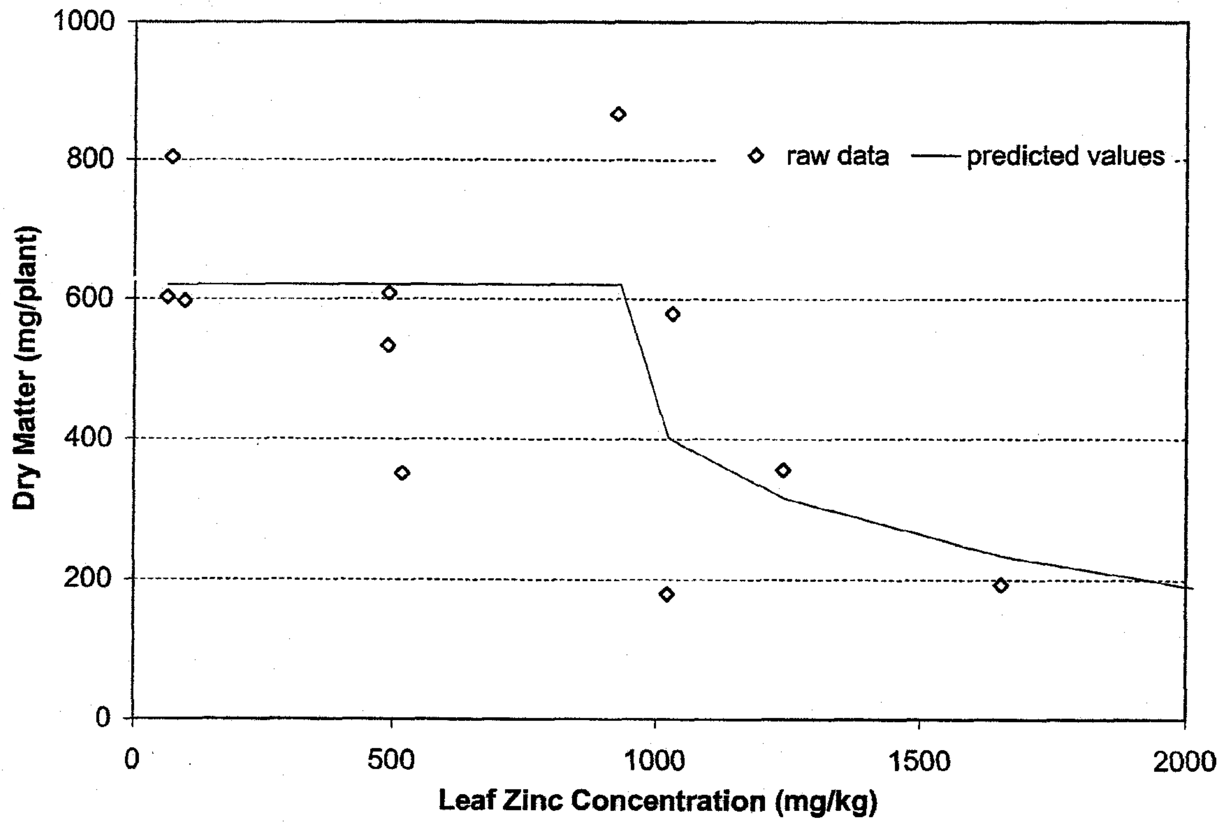

FIGURE AIII-7: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR CORN

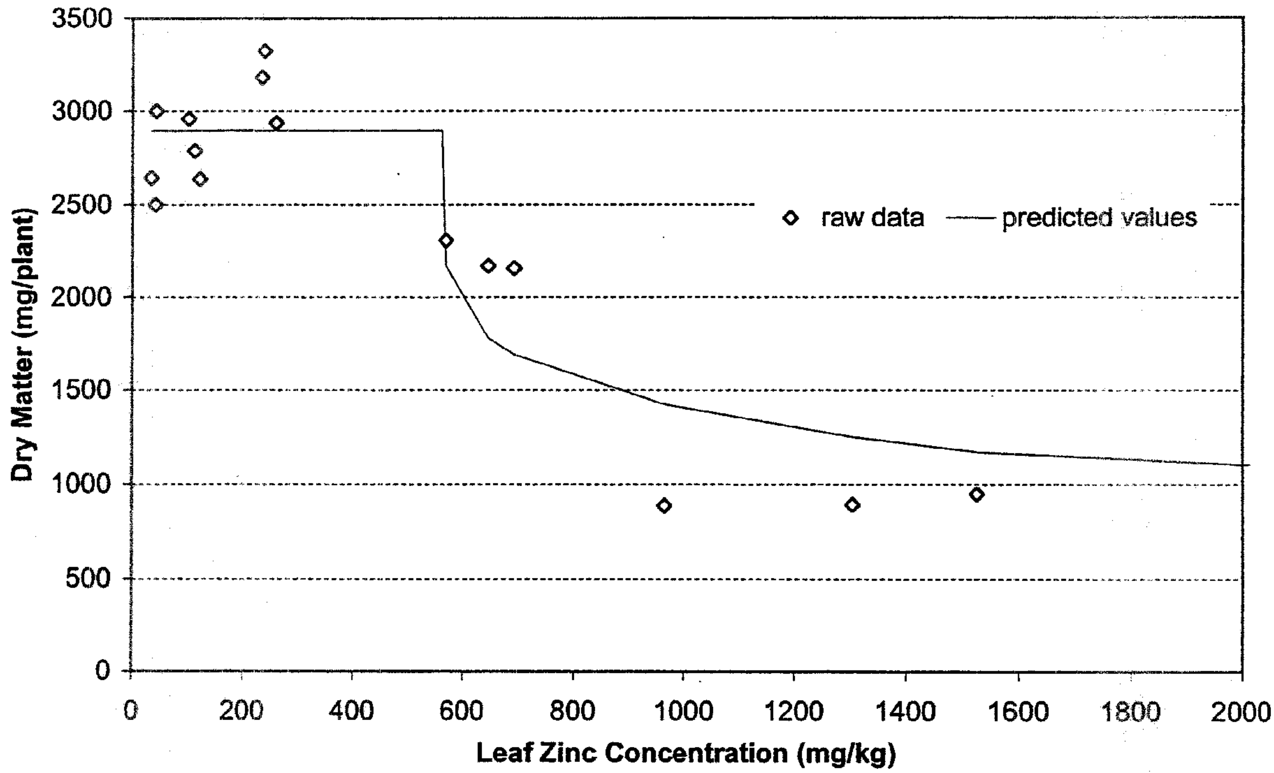

FIGURE AIII-8: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR COTTON

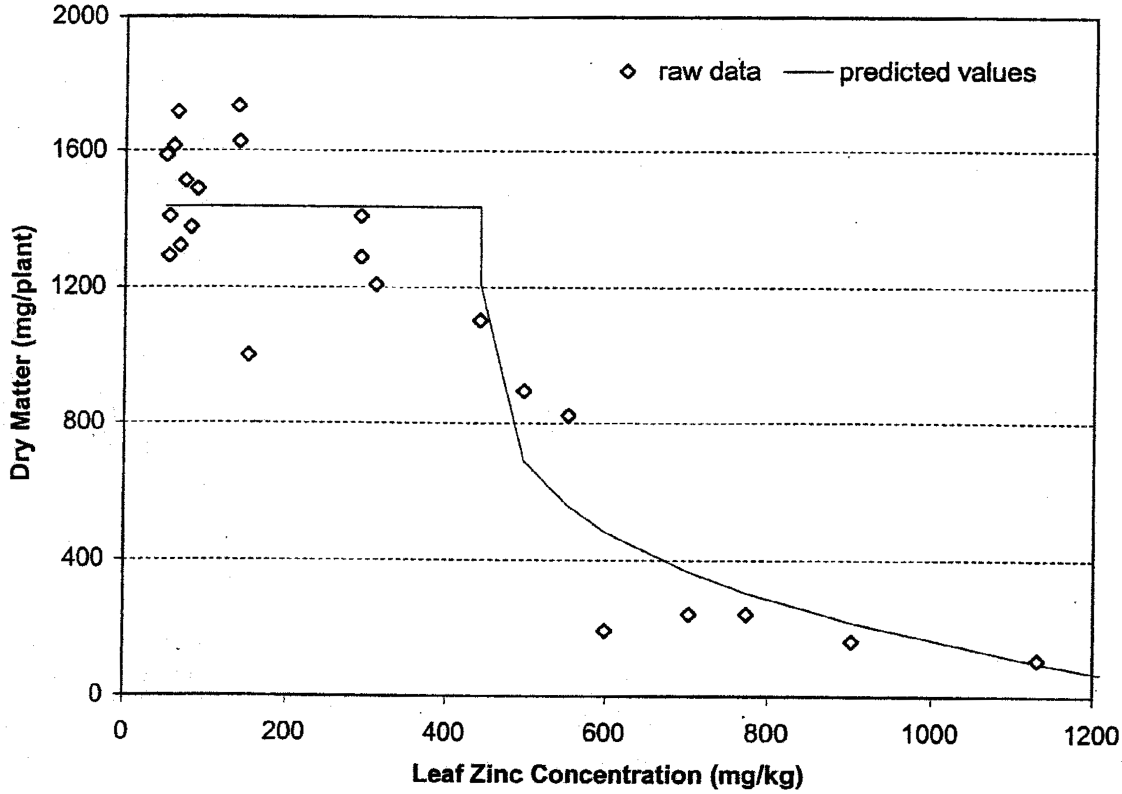

FIGURE AIII-9 OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR CREEPING BENTGRASS

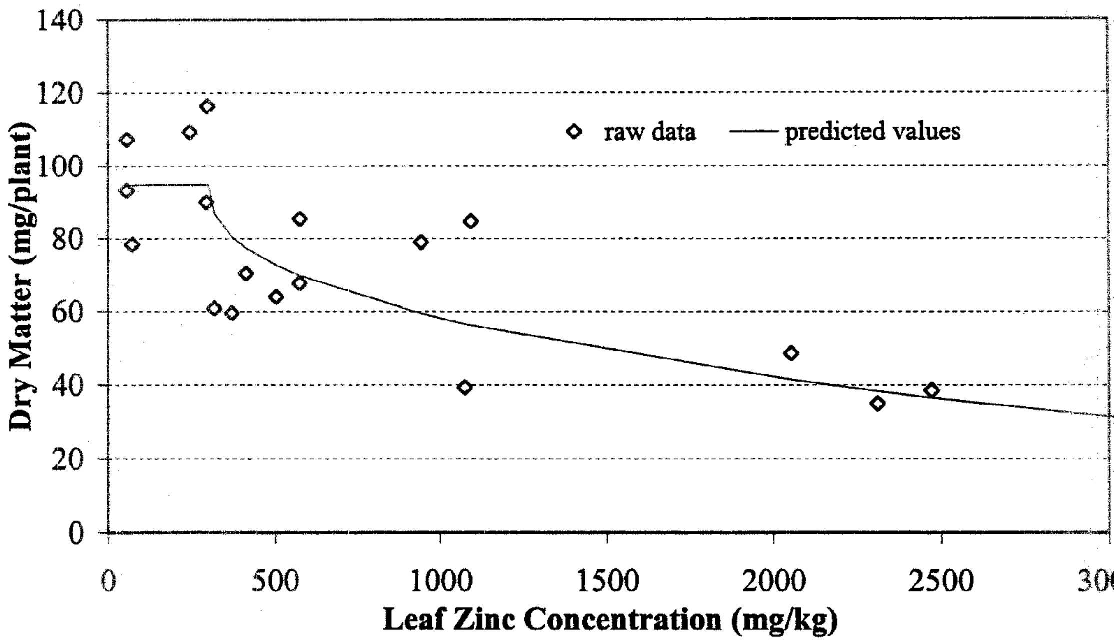

FIGURE AIII-10: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR KENTUCKY BLUEGRASS

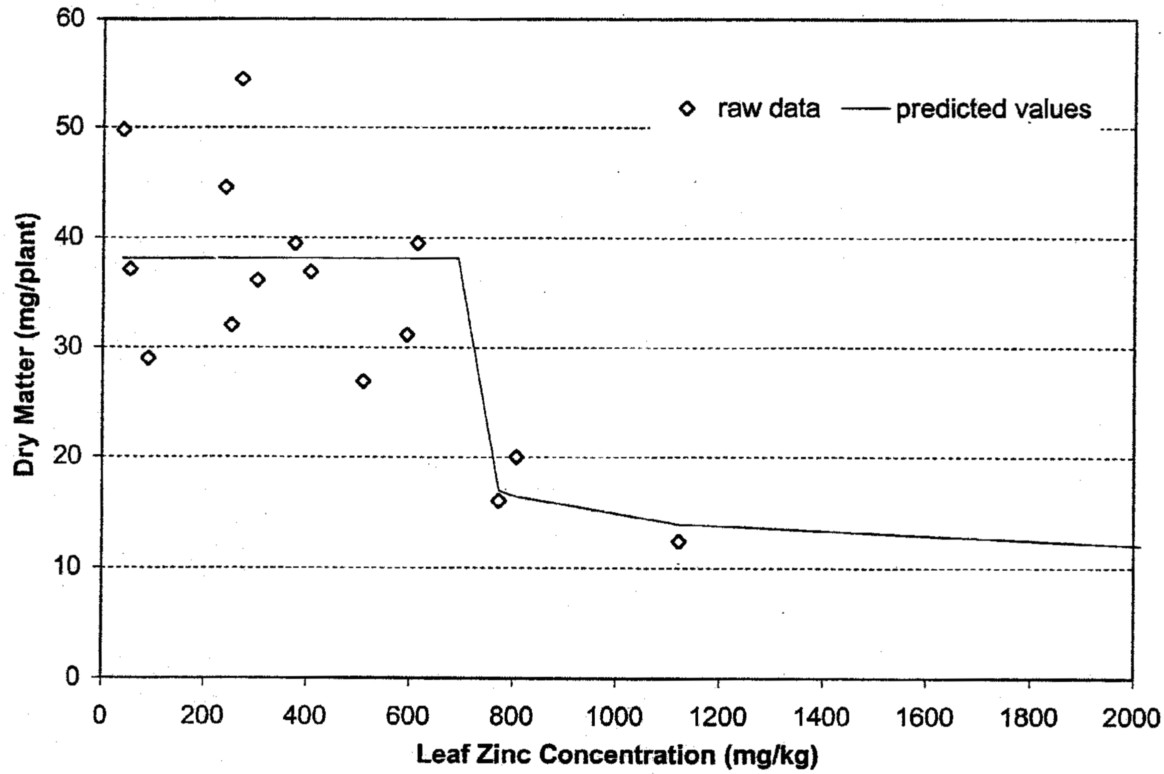

FIGURE AIII-11: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR LETTUCE, VARIETY BLACK SEEDED SIMPSON, GROWN IN 1998

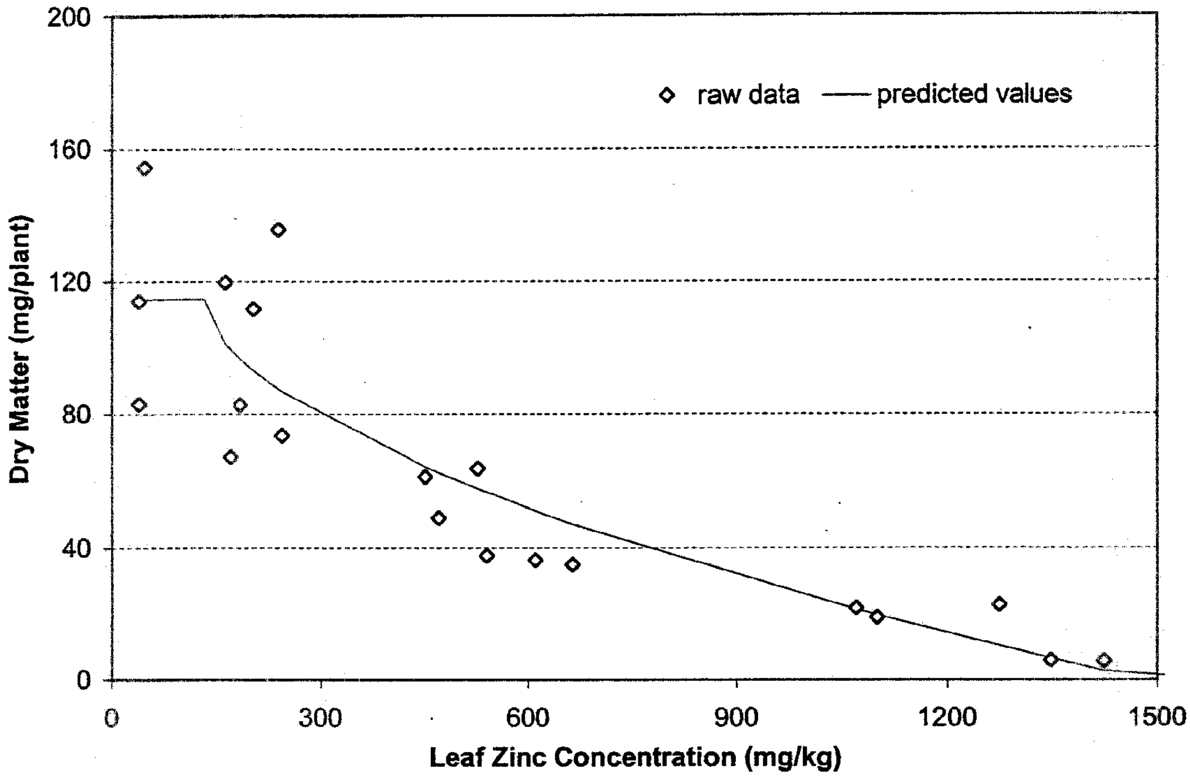

FIGURE AIII-12: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR LETTUCE, VARIETY BLACK SEEDED SIMPSON, GROWN IN 1999

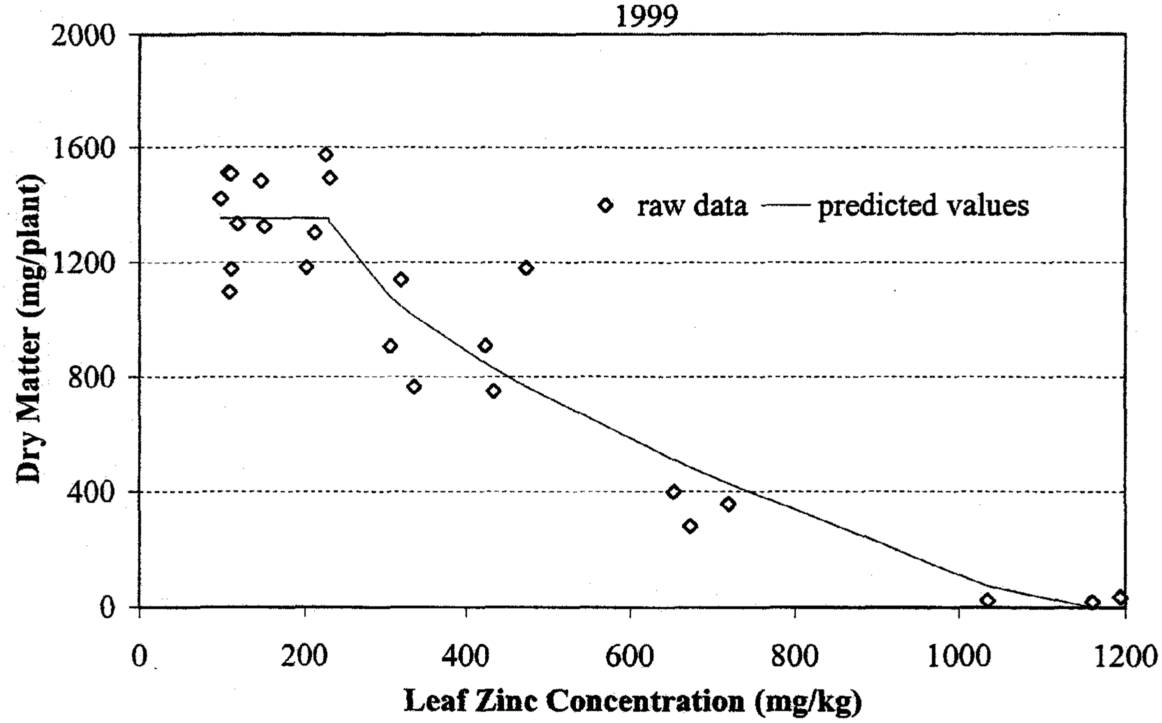

FIGURE AIII-13: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR LETTUCE, VARIETY ICEBERG

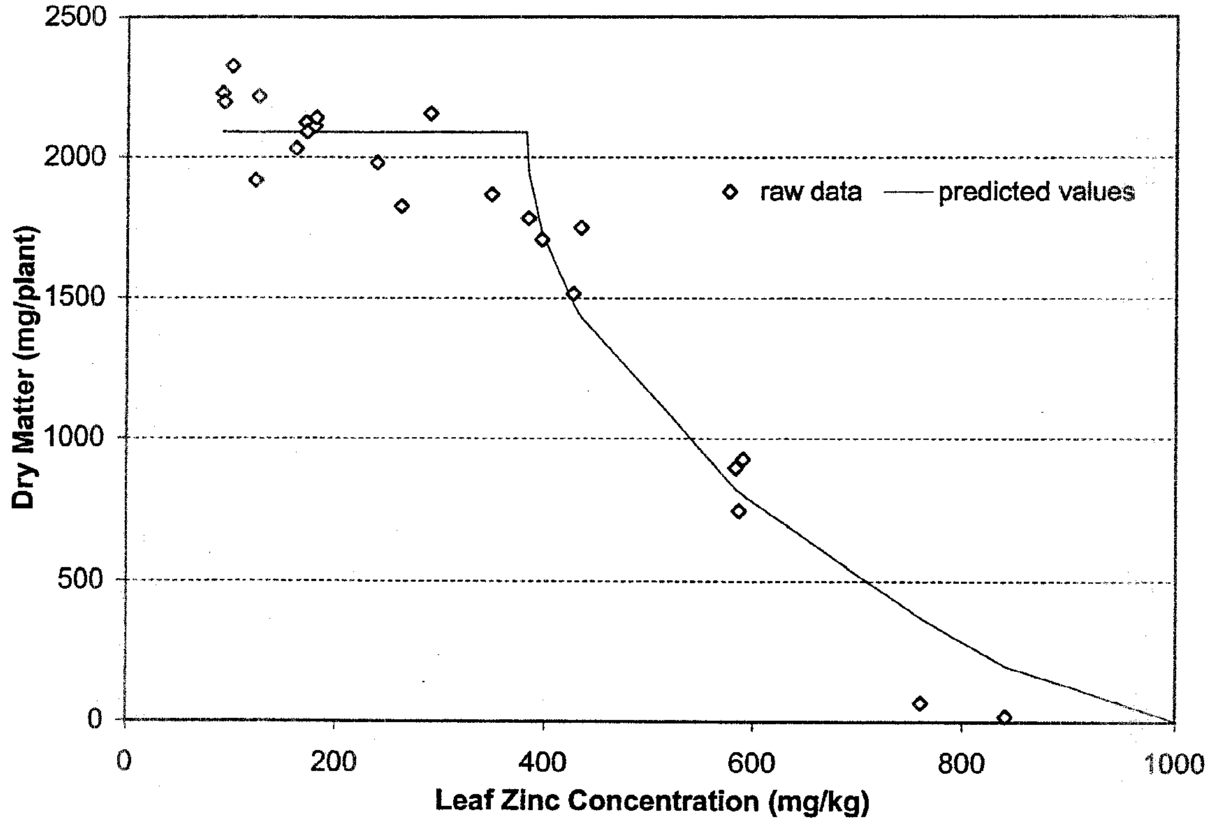

FIGURE AIII-14: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR OAT

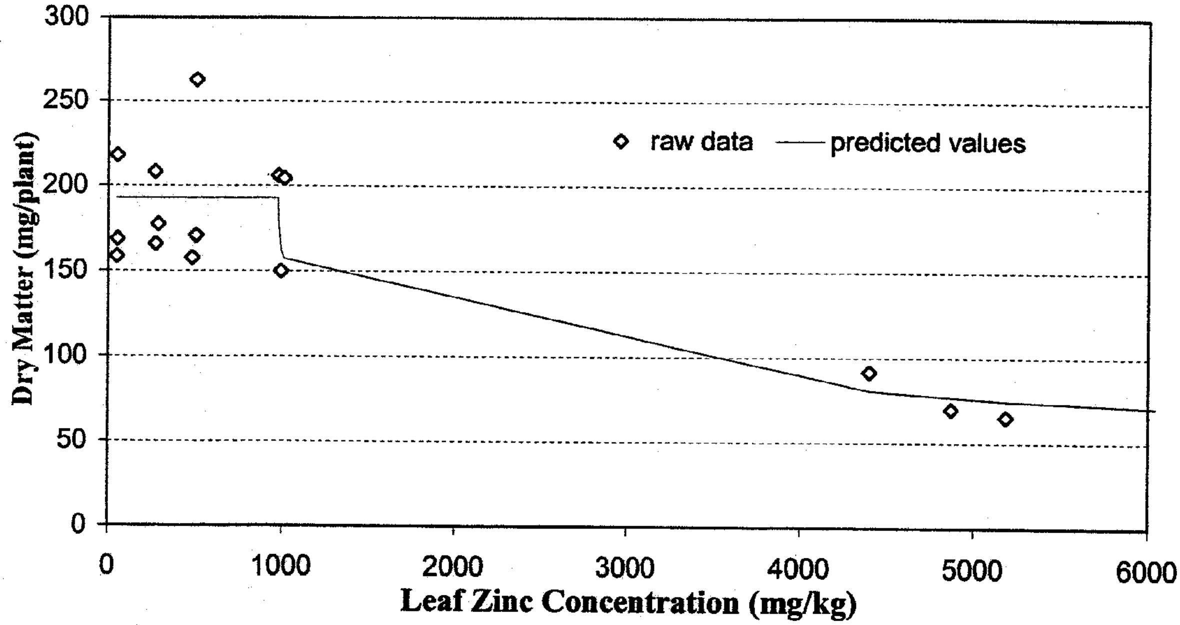

FIGURE AIII-15: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR PERENNIAL RYEGRASS

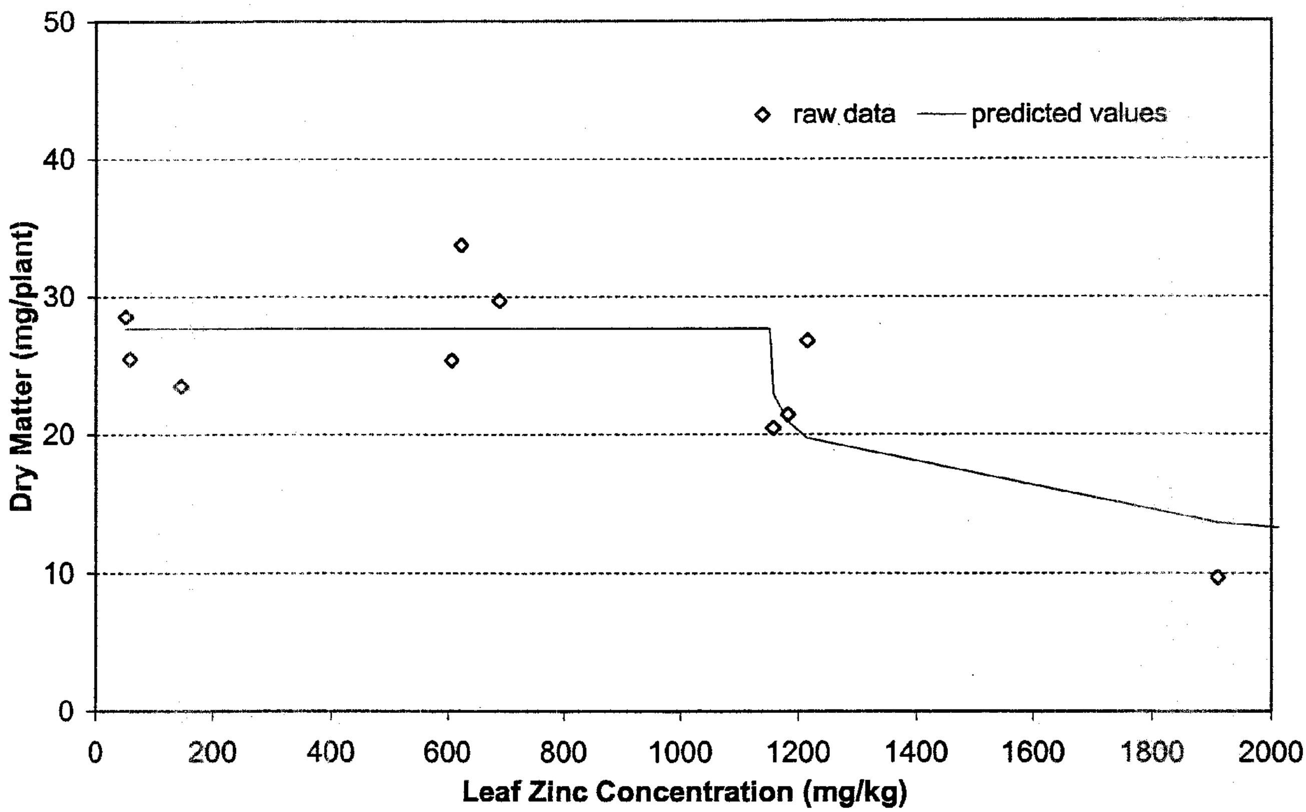

FIGURE AIII-16: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR RED TOP

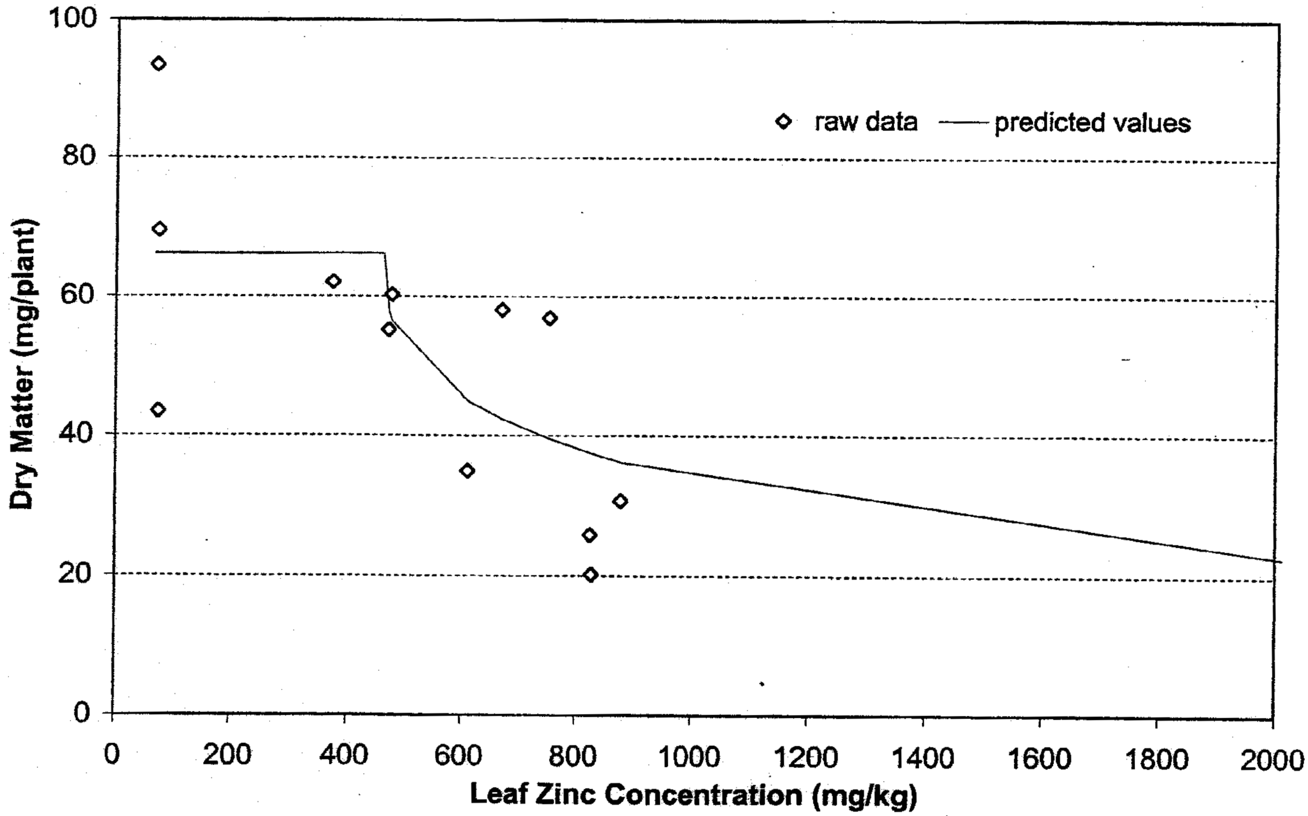

FIGURE AIII-17: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR REED CANARY GRASS

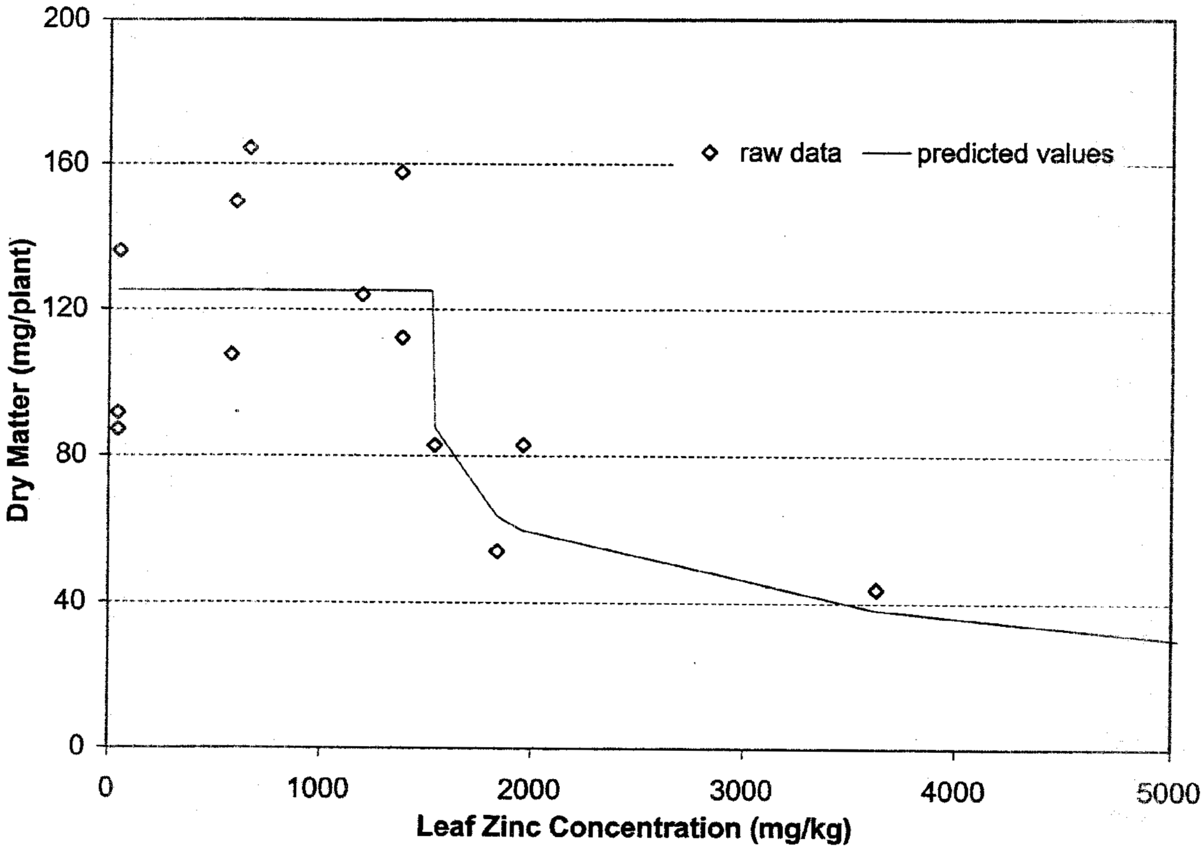

FIGURE AIII-18: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR SPINACH

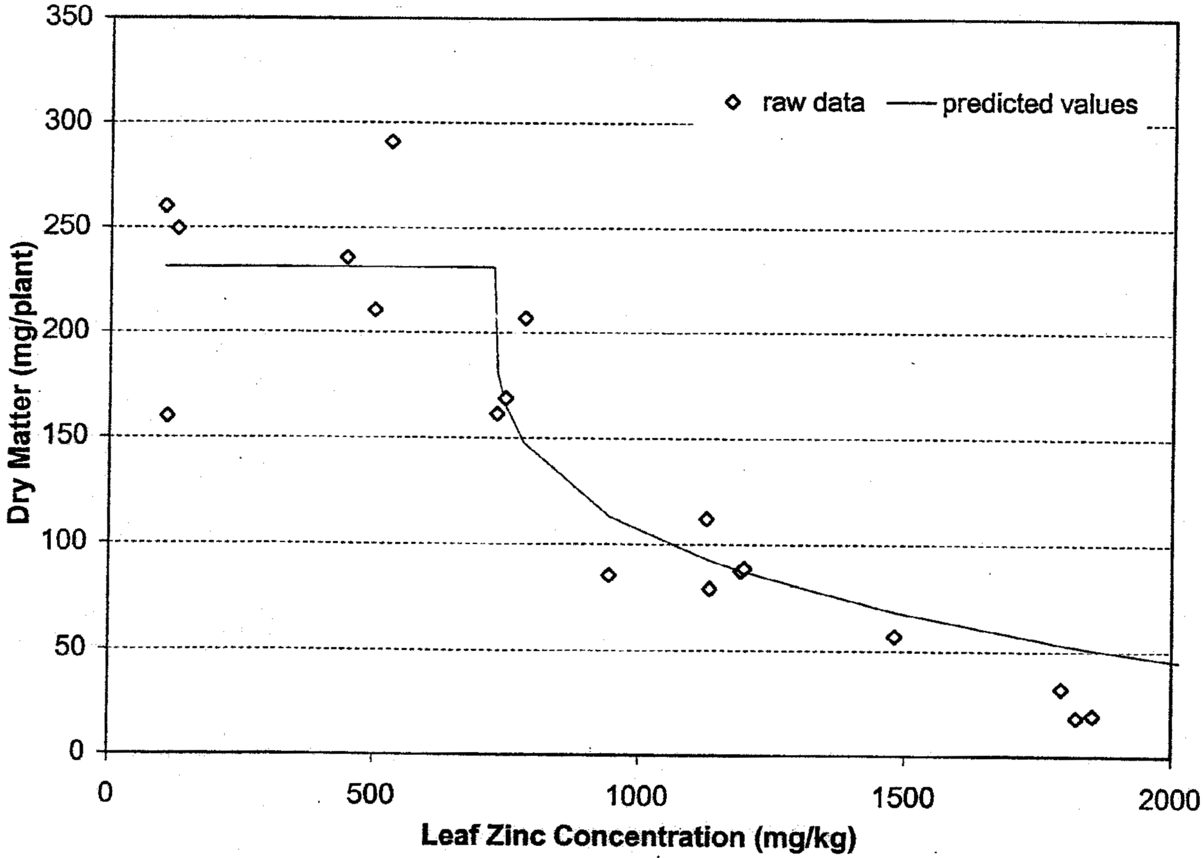

FIGURE AIII-19: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR TALL FESCUE

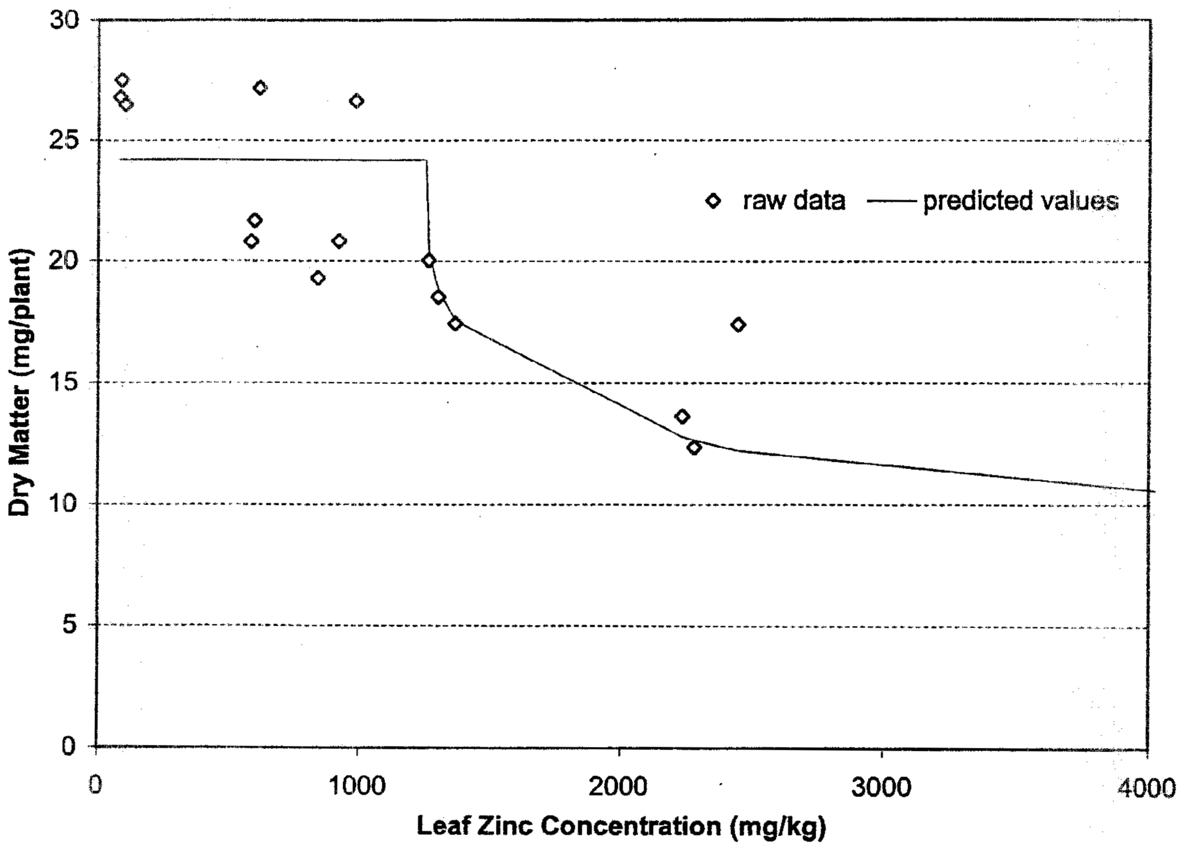

FIGURE AIII-20: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR TOMATO GROWN IN 1998

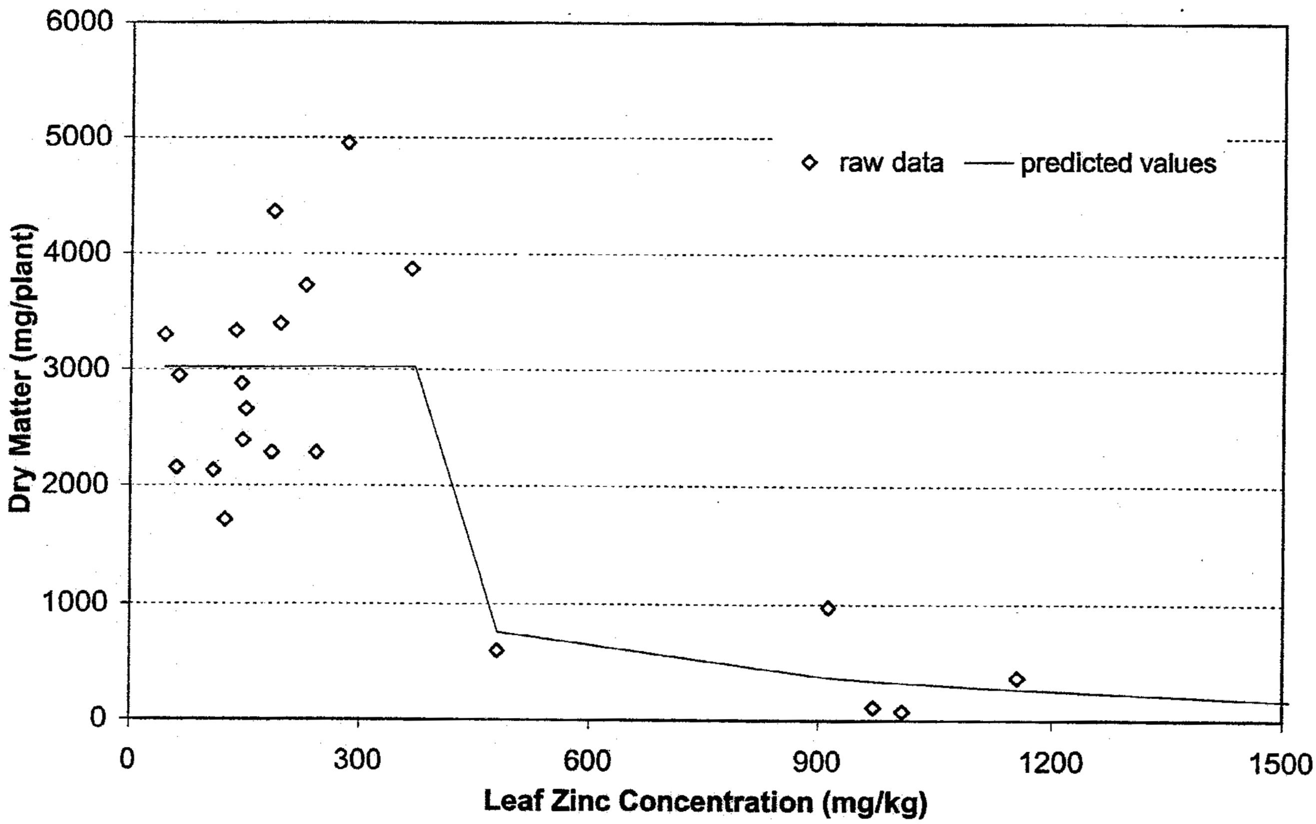

FIGURE AIII-21: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR TOMATO GROWN IN 1999

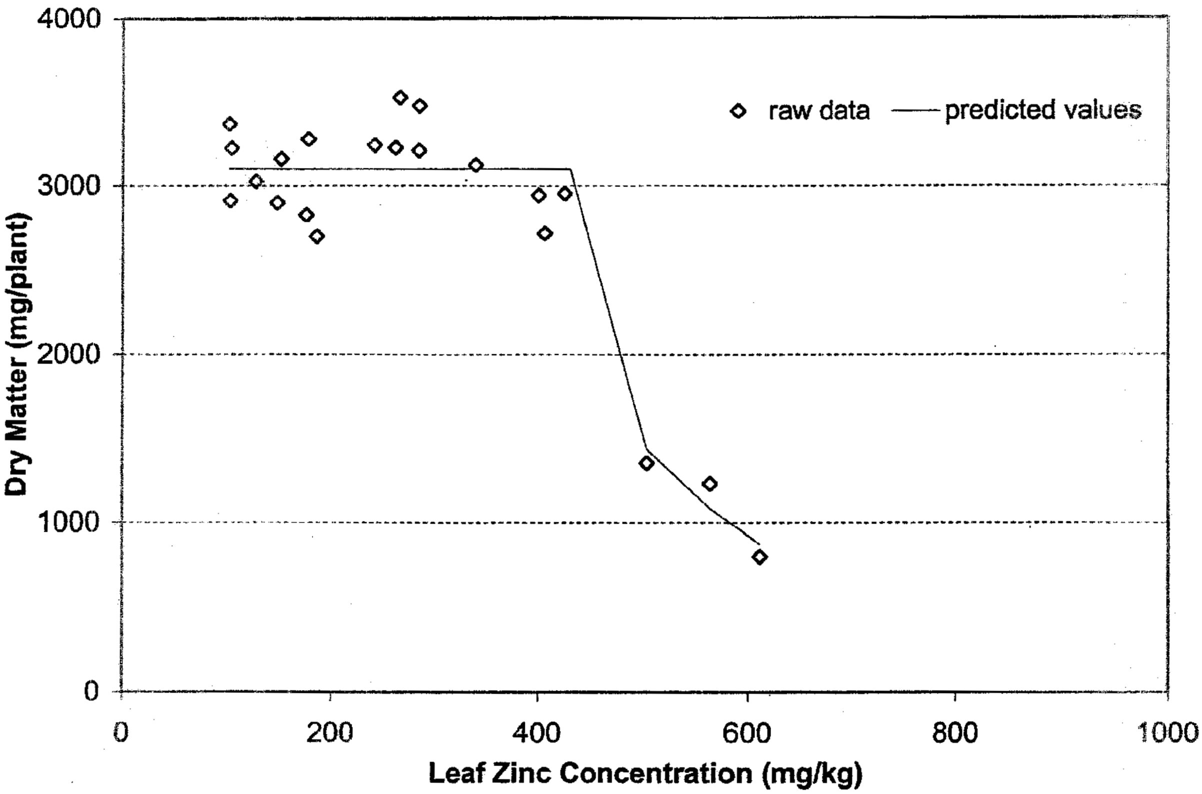

FIGURE AIII-22: OBSERVED AND SINGLE-KNOT SPLINE MODEL PREDICTED PLANT DRY MATTER PRODUCTION ASSOCIATED WITH LEAF Zn CONCENTRATIONS FOR WHEAT