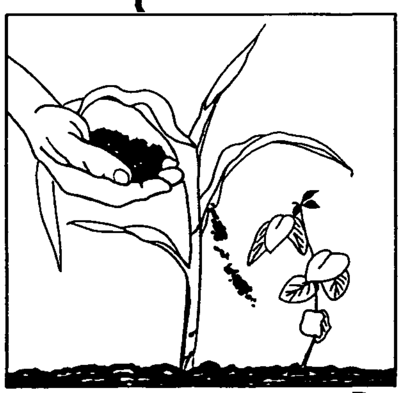
ISWS/RI-113/90
REPORT OF INVESTIGATION 113
STATE OF ILLINOIS
DEPARTMENT OF ENERGY AND NATURAL RESOURCES

# *Two-Year Study of Alum Sludge Application to Corn and Soybean Farmland*

by SHUN DAR LIN and C. DAVID GREEN



ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1990

**REPORT OF INVESTIGATION 113**

# *Two-Year Study of Alum Sludge Application to Corn and Soybean Farmland*

by SHUN DAR LIN and C. DAVID GREEN

**Title:** Two-Year Study of Alum Sludge Application to Com and Soybean Farmland.

**Abstract:** A two-year field study was conducted to assess the impact of applying air-dried alum sludge to farmland used for growing com and soybeans. Alum sludge was applied at four rates (0,2.5, 10, and 20 tons/acre) with three replicate test plots for each rate. Sludge was applied once, in the first year of the study (1986). Determinations were made of the effects of alum sludge application on soil properties, com and soybean yields, and plant parameters. Determinations also were made of the uptake and accumulation of heavy metals and nutrient levels in whole plants, leaf tissues, and grains. The 29 soil properties measured showed no significant effects of the alum sludge applications in either com or soybean plots. Differences in com yields were observed only in 1986; however, these were not due to alum sludge applications. For both years, other com plant parameters and soybean yield and plant parameters were not affected by alum sludge applications. The levels of plant nutrients and heavy metals in grains, whole plants, and leaves were also not significantly changed by the alum sludge applications. Application of air-dried alum sludge to farmland appears to have no beneficial or adverse effects on soil and crops, and led to no apparent environmental degradation. Therefore it may be a feasible alternative for sludge disposal.

**Reference:** Lin, Shun Dar, and C. David Green. Two-Year Study of Alum Sludge Application to Com and Soybean Farmland. Illinois State Water Survey, Champaign, Report of Investigation 113, 1990.

**Indexing Terms:** Alum sludge, chemical analysis, com (field), crop response, plant growth, plant tissues, residues, sludge disposal, soil amendments, soil properties, soybeans.

**STATE OF ILLINOIS**
**HON. JAMES R. THOMPSON, Governor**

**DEPARTMENT OF ENERGY AND NATURAL RESOURCES**
**Karen A. Witter, M.S., Director**



**STATE WATER SURVEY DIVISION**
**RICHARD G. SEMONIN, Chief**

**2204 GRIFFITH DRIVE**
**CHAMPAIGN, ILLINOIS 61820-7495**

**1990**

***Primed by authority of the State of Illinois***

**(12-90-100)**

Funds derived from grants and contracts administered by
the University of Illinois were used to produce this report.

# CONTENTS

PAGE


Abstract ... 1
Introduction ... 1
Objectives ... 2
Acknowledgments ... 2
Materials and Methods ... 3
Alum Sludge ... 3
Test Plots ... 3
Field Operation ... 3
Sample Collections ... 4
Soil Samples ... 4
Leaf Tissues ... 4
Harvest (Grains) ... 4
Whole Plant Tissues ... 5
Field Measurements ... 5
Yield ... 5
Plant Population ... 6
Soybean Height ... 7
Laboratory Analyses ... 7
Statistical Analyses ... 7
Results and Discussion ... 9
Background Information ... 9
Effects on Soil Properties ... 9
Total Solids ... 9
Organic Matter ... 9
Moisture Content ... 9
Bulk Density ... 12
pH ... 12
Acidity ... 12
Ammonia-Nitrogen ... 14
Nitrate-Nitrogen ... 14
Kjeldahl- and Total Nitrogen ... 14
Cation Exchange Capacity ... 17
BrayP-1 ... 17
Total Phosphorus ... 17
Potassium ... 19
Total Aluminum ... 19
Boron ... 20
Cadmium ... 20
Calcium, Chromium, and Copper ... 20
Total Iron ... 20
Lead ... 20
Magnesium ... 24
Manganese ... 24
Nickel ... 24
Zinc ... 24
Particle Size Distribution ... 24
General Observations ... 28
Corn Yields and Plant Parameters ... 28
Soybean Yields and Plant Parameters ... 29
Corn Grain Analysis ... 29
Soybean Grain Analysis ... 30
Corn Plant Tissue ... 30
Soybean Plant Tissue ... 33
Corn and Soybean Leaf Tissue ... 33
Summary ... 35
Conclusions ... 36
Recommendations ... 36
References ... 37
Appendices ... 38

# Two-Year Study of Alum Sludge Application to Corn and Soybean Farmland

*by Shun Dar Lin and C. David Green*

## ABSTRACT

A two-year field study was conducted to assess the impact of applying air-dried alum sludge to farmland used for growing corn and soybeans. The study was carried out at the Northwestern Agricultural Research and Demonstration Center of the University of Illinois. Alum sludge was applied at four rates (0,2.5, 10, and 20 tons/acre) with three replicate test plots for each rate. Sludge was applied once, in the first year of the study (1986).

Determinations were made of the effects of alum sludge application on soil properties, corn and soybean yields, and plant parameters. Determinations also were made of the uptake and accumulation of heavy metals and nutrient levels in whole plants, leaf tissues, and grains. The collected data were analyzed by the least-significant-differences method.

The 29 soil properties measured showed no significant effects of the alum sludge applications in either corn or soybean plots. Differences in corn yields were observed only in 1986; however, these were not due to alum sludge applications. For both years, other corn plant parameters and soybean yield and plant parameters were not affected by alum sludge applications. The levels of plant nutrients and heavy metals in grains, whole plants, and leaves were also not significantly changed by the alum sludge applications.

Application of air-dried alum sludge to farmland appeared to have no beneficial or adverse effects on soil and crops, and led to no apparent environmental degradation. Therefore it may be a feasible alternative for sludge disposal.

## INTRODUCTION

The treatment processes at water treatment plants may include aeration, coagulation, sedimentation, softening, iron and manganese removal, and disinfection (with or without other treatments). With the exception of disinfection (chlorination is commonly used), each water treatment process generates residues, either solids, liquids, semi-solids, or brines. The waste residues consist mainly of impurities in the raw water and small quantities of residues produced by the chemical treatments.

The type, quantity, and properties of the residues generated by water treatment plants vary depending on many factors. The major types of waste streams from water treatment plants are alum sludge retained in flocculators and sedimentation basins, washwaters generated from filter backwash operations (alum sludge and/or lime sludge), lime sludge precipitates from the lime softening process, brines from the ion-exchange (zeolite) softening process, iron removal sludge from iron filter backwash wastewater, and sand and iron sludge removed from the slow sand filters.

Alum is the most widely used primary coagulant in Illinois and in the nation. Activated silica, clay, and a variety of polymers are used as coagulant aids. Alum coagulation process residues may contain aluminum hydroxide, sand, clay, colloidal material, inorganic and organic matter, and microorganisms.

Residues of alum coagulation and sedimentation have feathering and gelatinous characteristics with a moisture content of approximately 98.5 to 99.0 percent. They vary in color from light yellow-brown to solid black (if powdered activated carbon is added). Alum sludge settles readily but does not dewater easily.

In the past, water plant residues have been discharged to the nearest drainage courses or receiving waters. Federal and state regulations classsify water treatment plant wastes (residues or sludge) with other industrial wastes and prohibit their direct discharge, except in certain cases. All sludge generators in Illinois are responsible for the proper disposal of sludge and must provide details of their plans for the ultimate disposal of sludge to the Illinois Environmental Protection Agency (IEPA) as a part of any permit application for any facility that will generate sludge.

As defined by the IEPA (1982), sludge is considered to be the process sidestream residue, which consists of a solid material removed from the mainstream process. Sludge includes any solids, semisolid, or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility or any other such waste facility with similar characteristics and effects.

In Illinois, the rules and regulations on ultimate sludge disposal are published in Title 35, Subtitle C, Chapter II, Part 391, "Design Criteria for Sludge Application on Land" (IEPA, 1984). A shorter version of the guidelines on sludge regulation is published in "Illinois EPA Sludge Regulation Guidance Document" (IEPA, 1982). These documents give direction to sludge generators, handlers, users, consultants, and the general public.

Present sludge disposal practices of water treatment plants in Illinois include lagooning, landfilling, agricultural use, and burying of sludge on plant property. Sludge may also be incinerated or may be used in silviculture or horticulture, as a construction filling material, or for landscaping. Many water plants will soon run out of lagooning space. Ultimately, the dried sludge has to be disposed of somewhere. This is the problem encountered in the water industry.

Although alum sludge from water treatment plants is not considered a hazardous waste, the IEPA states that alum sludge has a tendency to cause soil to harden and that it does not provide any beneficial value. For this reason, the sludge must not be applied to agricultural land (IEPA, 1982). However, complete and pertinent data on the land application of alum sludge is lacking. For example, the use of alum sludge on agricultural land may have nutritional benefits. On the other hand, possible disadvantages are that phytotoxicity of metals in sludge might reduce crop yields; uptake and accumulation of heavy metals in plant tissue and crops might make crops unsafe for animal or human consumption; alum sludge might be toxic to soil microorganisms that degrade organic compounds in the sludge; and constituents in the sludge might pollute ground water, thereby posing a public health threat.

## Objectives

The purpose of this study was to assess the benefits and risks of alum sludge application to farmland used for growing corn and soybeans. The study was intended to address some of the concerns regarding alum sludge application to farmland stated above. The effects of the alum sludge in the second year after application were also examined.

The specific objectives were to monitor 29 characteristics of the soils in the test plots, the uptake and accumulation of heavy metals by plants, other nutrients in plant tissues, crop yields, and other plant parameters.

## Acknowledgments

The first-year study was fully sponsored by a grant from the Illinois Department of Energy and Natural Resources (ENR). The cooperation of the ENR project manager, Tom Heavisides, and of Michael Mainz of the University of Illinois is gratefully acknowledged. Mr. Mainz also assessed crop yields and plant parameters, oversaw field operations and field measurements, and prepared the samples of ground grains, leaves, and whole plants.

This study was conducted under the general administrative direction of Richard Semonin, Chief of the Illinois State Water Survey, and Raman Raman, Director of the Office of Water Quality Management. The authors are grateful to other members of the Water Survey who participated. Dave Hullinger, Dana Shackleford, and Bill Cook performed chemical analyses. The late Harvey Adkins assisted in alum sludge hauling. Linda Johnson typed the original manuscript, and Gail Taylor edited the report.

# MATERIALS AND METHODS

## Alum Sludge

Alum sludge was hand-shoveled from a sludge lagoon at the Peoria water treatment facility (Illinois-American Water Company) and dried on the driveway of the lagoons on March 27, 1986. The sludge was turned over several times to aid in its drying.

On April 7, 1986, a truckload (about 20 tons) of dry alum sludge was transported to the test site. The dry sludge was stored inside a shelter near the test site until application. It proved impossible to break apart the lumps of sludge by hand during application, and many of these small clods were still visible at harvest.

## Test Plots

The field study was conducted at the Northwestern Agricultural Research and Demonstration Center of the University of Illinois, Monmouth, Illinois. The soils at this site are Tama silt loam, Muscatine silt loam, and Sable silty clay loam, which are typical of much of the agricultural land in Illinois.

Each test plot was 15 x 30 feet (4.6 x 9.2 meters) with a 4.6-meter border area around all the plots. For each crop grown, three replicate plots were used for a control and for each of three sludge application rates.

During the first year of the study, treatments were applied in a randomized block design for corn and in a completely randomized design for soybeans. In the second year, the crops were reversed between the two groups of test plots. The dried alum sludge was applied only once (during 1986), and its impact was investigated during the growing seasons of 1986 and 1987.

## Field Operation

The fieldwork schedules for the first and second years are summarized in tables 1 and 2, respectively. The tables list the dates of tillage, fertilizer and herbicide applications, weed control, sludge application, planting, and collection of soil samples. The major fieldwork was carried out from April through October in both 1986 and 1987.

Prior to sludge application, 150 pounds per acre (lb/a) of phosphorus as $P_2O_5$ was applied to the soybean plots, including the border areas. Anhydrous ammonia was applied at a rate of 180 lb/a of nitrogen to the corn plots and border areas.

Alum sludge applications were made prior to planting in 1986 only. No sludge was applied in 1987. The four sludge application rates were zero (control), 2.5, 10.0, and 20.0 tons/acre (t/a), which are equivalent to 0, 0.56, 2.24, and 4.48 kilograms of dry sludge per square meter of land, respectively. Sludge was spread by hand on April 22, 1986, and was then incorporated with a disk to a depth of 4 inches (10 centimeters). Each area was disked and harrowed again prior to planting.

Sieben-brand 35XS corn was planted at 26,600 seeds per acre on April 24, 1986. Counter 15G insecticide was applied with the planter to control rootworms. Sieben-brand 235 soybeans were planted in 30-inch rows on May 23, 1986, at a rate of approximately 165,000 seeds/acre. Ridomil (6.67 lb/a) and Amiben 10G (10 lb/a) were added with the planter to control insects and weeds, respectively.

A preemergence application of Bicep (3 qt/a) and Bladex 80W (0.6 lb/a) gave excellent weed control in the corn plots. Amiben DS (2.6 lb/a) and Dual (3 pt/a) controlled most of the weeds in the soybean plots. Field bindweed was controlled in the soybean plots with a spot application of Roundup. The corn was cultivated once in June 1986.

For the 1987 fieldwork, anhydrous ammonia was applied to the corn test plots on April 9 at the rate of 180 lb/a of nitrogen, as shown in table 2. The corn test plots were disked and harrowed on April 25, and the soybean plots on May 11. Sieben 43XS hybrid corn (27,700 seeds/a) was planted on April 27, and FS brand 265 soybeans (150,000 seeds/a) were planted on May 11.

On April 28, 1987, composite soil samples were pulled from each test plot. Preemergence herbicides (Dual, Bladex, and Atrazine) were applied to the corn plots on May 5, and Lasso MT and Amiben DS were applied to the soybean plots on May 18. The corn test plots were cultivated on June 8.

Postemergence herbicides (Fusilade 2000, Basagran, Reflex, and crop oil concentrate) were applied to the soybean plots on June 5 and June 19. On June 24, weeds in the soybean plots were hoed by hand.

In 1987, leaf tissue samples were taken on July 10 for corn and on July 21 for soybeans. Harvesting and collection of plant tissue and grain samples were carried out on October 5 for soybeans and on October 7 for corn. Additionally, three composite soil samples were pulled from each plot during the study.

**Table 1. Field Record for 1986**

| | |
|---|---|
| *Corn test plots* | |
| 4/3/86 | Applied anhydrous ammonia at 180 lb/a of nitrogen |
| 4/22/86 | Applied sludge, disked (8-ft disk) to incorporate sludge to 4 inches in depth |
| 4/24/86 | Pulled soil samples, planted Sieben 35XS, Counter 15G, 8.7 lb/a (26,600 k/a), disked with harrow |
| 4/29/86 | Preemergent Bicep applied at 3 qt/a (Dual 1.875 lb/a, Atrazine 1.5 lb/a), and Bladex 80W at 0.6 lb/a (0.5 lb/a active ingredient) was applied |
| 5/3-4/86 | Plant emergence |
| 6/3/86 | Cultivation |
| 6/13/86 | Pulled soil samples |
| 7/21/86 | Leaf samples taken |
| 8/13/86 | Pulled soil samples |
| 10/21/86 | Pulled soil samples, harvested |
| *Soybean test plots* | |
| 11/7/85 | Soil sampled (Research Center) |
| 11/8/85 | Applied 150 lb/a of $P_2O_5$ |
| 11/21/85 | Chisel-plowed |
| 4/2/86 | Disked |
| 4/22/86 | Applied sludge, disked with 8-ft disk to incorporate sludge to 5 inches in depth |
| 5/6/86 | Disked with harrow |
| 5/21/86 | Disked with harrow twice, pulled soil samples |
| 5/23/86 | Planted with Sieben 235 (165,000 seeds/a), applied Ridomil 6.67 lb/a and Amiben (granule) 10 lb/a in a 10-inch band |
| 5/29/86 | Applied Amiben DS 2.6 lb/a and Dual 3 pt/a |
| 7/18/86 | Pulled soil samples |
| 7/21/86 | Leaf samples taken |
| 8/29/86 | Pulled soil samples |
| 10/21/86 | Pulled soil samples, harvested |

## Sample Collections

### *Soil Samples*

Soil samples were pulled with a Hoffer soil sampling tube to a depth of 6 inches (15 cm). The sampler is 3/4 inch (1.9 cm) in diameter and 36 inches (91 cm) in length. Eight soil samples were pulled and composited for each test plot. The soil samples were refrigerated until they were analyzed. During each year of the study, soil samples were collected in April for each test plot and then every other month during the growing season (tables 1 and 2).

### *Leaf Tissues*

When pollination started, one corn leaf opposite and below the ear was cut off for tissue analyses. Ten corn leaves were cut per test plot. For soybeans, the uppermost fully expanded trifoliate was cut from the stem. Fifteen soybean leaves were collected per test plot. The leaf samples, as well as the whole plant tissues and grains, were ground at the Orr Research Center of the University of Illinois.

### *Harvest (Grains)*

The corn ears in the two center corn rows were harvested by hand (the remaining rows were later machine-harvested). The total weight of the harvested corn ears was determined with a tripod scale and then averaged for each treatment. Several ears from each row were shelled (figure 1) to determine the shelling percentage (weight of grain/weight of corn ear), grain moisture, and test weight.

**Table 2. Field Record for 1987**

| | |
|---|---|
| *Corn test plots* | |
| 4/9/87 | Applied anhydrous ammonia at 180 lb/a of nitrogen |
| 4/25/87 | Disked and harrowed |
| 4/27/87 | Planted Sieben 43XS hybrid corn at 27,700 seeds/acre |
| 4/28/87 | Pulled soil samples |
| 5/5/87 | Preemergence herbicide application: Dual (3.0 pts/a), Bladex (0.8 qt/a), Atrazine (0.8 qt/a) |
| 6/8/87 | Cultivated |
| 7/10/87 | Leaf tissue samples taken |
| 7/17/87 | Pulled soil samples |
| 9/4/87 | Pulled soil samples |
| 10/7/87 | Machine-harvested corn plots (collected residue and grain samples) |
| 10/15/87 | Pulled soil samples |
| *Soybean test plots* | |
| 4/28/87 | Pulled soil samples |
| 5/11/87 | Disked and harrowed |
| 5/11/87 | Planted FS brand 265 soybeans (150,000 seeds/a) in 30 inch rows |
| 5/18/87 | Preemergence herbicide application: Lasso MT (3.0 qt/a) and Amiben DS (2.6 lbs/a) |
| 6/5/87 | Postemergence herbicide application: Fusilade 2000 (0.75 pt/a), Crop oil concentrate (1.0 qt/a) |
| 6/19/87 | Postemergence herbicide application: Basagran (1 qt/a), Reflex (0.8 pt/a), Crop oil concentrate (1 qt/a) |
| 6/24/87 | Hoed (hand-weeded) the weeds |
| 6/26/87 | Pulled soil samples |
| 7/21/87 | Leaf tissue samples taken |
| 8/21/87 | Pulled soil samples |
| 10/5/87 | Machine-harvested soybean plots (residue and grain samples taken) |
| 10/15/87 | Pulled soil samples |

The two center soybean rows were harvested with a Hagie plot combine (see figure 2). The grain was then air-dried in a grain bin and ground with a Bur mill.

### *Whole Plant Tissues*

Five corn plants were cut randomly at the time of harvest for analyses of plant tissues. In conformance with general practice, this did not include roots or corn ears. Soybean plant tissues were collected with a paper grocery shopping bag from the residue left at the rear-end of the plot combine during harvesting. The plant tissues were ground by a Willey mill.

## Field Measurements

Field measurements were made on grain weight, corn and soybean plant populations, and soybean height.

### *Yield*

The total weight of six to eight corn ears before shelling and the total weight of the cobs were measured. The difference between these two measurements represents the weight of the kernels. The percentage of kernel weight compared to the total weight was then determined.

Figure 1. Shelling corn

Figure 2. Harvesting soybeans

The total weight of corn ears harvested from the two center rows was also measured. Multiplying the percentage of kernels and total harvested weight gave the grain weight for the two rows harvested in each test plot. Given the dimensions of the area and assuming 60 pounds per bushel, the corn yield can be calculated from the kernel weight and the size of the area. The corn yield is expressed in bushels per acre (bu/a) at 15.5 percent moisture.

Similarly, soybean yields were determined after measurements were made of the total weight of soybeans harvested and the growing area. Soybean yield is expressed in bushels per acre at 13 percent moisture content.

### *Plant Population*

For both corn and soybeans, the number of plants in two 5-foot-long sections were counted. On the basis of the area covered by these two 5-foot-long sections, the plant population was converted to number of plants per acre.

***Soybean Height***

The soybean height was measured in inches from the surface of the ground to the top of the main stem after the leaves fell. The heights of ten soybean plants per test plot were determined, and the average value is reported.

## Laboratory Analyses

In the laboratory, the following physical and chemical determinations were made on the soil samples: total solids, organic matter, moisture content, bulk density, pH, soil acidity, ammonia-nitrogen ($NH_3$-N), nitrate-nitrogen ($N0_3$-N), Kjeldahl-nitrogen, total nitrogen, cation exchange capacity (CEC), Bray P-l, total phosphorus, potassium, aluminum, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, nickel, zinc, and particle size distribution (percent sand, silt, and clay). For dry alum sludge, calcium carbonate equivalent (CCE) and citric acid soluble phosphorus were determined in addition to the above parameters, and soil acidity was not determined. The methods and procedures involved in these determinations are indicated in table 3.

Analyses of 11 metals were carried out on both corn and soybean grains, leaves, and whole plants. The metals were aluminum, cadmium, calcium, chromium, copper, iron, lead, magnesium, nickel, potassium, and zinc. The metal concentrations in soil samples as well as in leaves, grains, and plants were analyzed by atomic absorption (AA) spectrophotometry. However, the extraction procedures were different.

For the metal analyses of soil samples, 0.5 g of dried soil was placed in 75 mL of deionized water. One mL of metals grade HC1 and 1 mL of metals grade $HNO_3$ were added. The soil sample was heated to about 70°C until the volume was reduced to 25 mL. The volume was brought up to 50 mL by rinsing the sides of the beaker. Then 1 mL of $HNO_3$ was added and heated to 70"C until the volume was reduced to 25 mL. The solution was filtered through a 0.45 urn membrane, diluted to 50.0 mL, and analyzed by AA spectrophotometry.

For the metal analysis of the leaves, grains, and plant samples, 5.0 g of tissue sample were placed in 50 mL of 50 percent $HNO_3$ solution. The sample was allowed to sit for two hours and then was heated to 70°C until the $NO_2$ fumes were gone. Five mL of concentrated $HNO_3$ was added, and the solution was heated again at 70°C until the $NO_2$ fumes were gone. The beaker was cooled and 5.0 mL of concentrated HC1 was added. The beaker was again heated to 70"C until the volume was reduced to 30 mL.

The solution was then filtered with a 0.45 µm membrane and made up to a volume of 50 mL. The extractant solution was analyzed by AA spectrophotometry.

## Statistical Analyses

There are three general approaches to mean separation (determination of which treatment means are significantly different): the use of least significant differences (LSD), the use of Duncan's multiple-range tests, and the use of planned F tests (Little and Hills, 1978).

The LSD method is simplest and is the method most widely used by agronomists. For this study, the LSD method was used for mean separation. The LSD is used only to compare adjacent means in an array unless the F test shows a significant difference. LSD is calculated as follows:

$$\mathrm{LSD} = t\sqrt{\frac{S_1^2}{r_1} + \frac{S_2^2}{r_2}} \qquad (1)$$

where

t = a tabulated value determined by the degrees of freedom of the variance and the level of significance desired

$S_1^2$, $S_2^2$= the estimated variance of plots receiving treatments 1 and 2

$r_1$, $r_2$ = the number of experimental units receiving treatments 1 and 2, respectively

Assuming $S_1^2 = S_2^2 = S^2$ and $r_1 = r_2$, where $S^2$ = the mean square for error, then

$$\mathrm{LSD} = t\sqrt{\frac{2\,S^2}{r}} \qquad (2)$$

All the data (soils, grains, and tissues) obtained except for the pH and cadmium data were subjected to statistical analyses. In 1986 treatments were applied in a randomized block design for corn and in a completely randomized design for soybeans, and two-way and one-way analyses of variance were used for the corn and soybean data, respectively. In 1987 the treatments and statistical analyses were reversed for the two crops. Only when the F test is significant is LSD calculated by equation 2, with a confidence level of 90 percent.

**Table 3. Analytical Procedures**

| *Parameter* | *Method* |
|---|---|
| Total solids | % residue after evaporation at 110°C for 24 hrs |
| Moisture content | 100% minus % of total solids |
| Organic matter | % loss after 550° ± 50°C for 1 hr |
| Bulk density | *Methods of Soil Analysis* (Black, 1973), core method, p. 375 |
| pH | Measured on a slurry (10 g soil saturated with double distilled water) after stirring 4 times during a 30-min period |
| Soil acidity | *Methods of Soil Analysis* (Page, 1982), potassium chloride method, p. 163 |
| Calcium carbonate equivalent, CCE | *Methods of Soil Analysis* (Page, 1982), Part 2, pressure-calcimeter method, p. 188 |
| Cation exchange capacity, CEC | Modified by using a centrifuge instead of fiitration (Wang, 1975) |
| Ammonia-nitrogen, NH,-N | *Methods of Soil Analysis* (Page, 1982), distilled with HBO,, pp. 653-654, and analyzed by the indophenol blue method, p. 674 |
| Nitrate-nitrogen, NO,-N | Dried soil is extracted with 0.02 N $CuSO_4$ solution containing $Ag_2SO_4$ (Jackson, 1958). The extract is analyzed by the chromotropic acid method *of Standard Methods*, 16th ed., 1985, 418 D |
| Total Kjeldahl-nitrogen | *Methods of Soil Analysis* (Page, 1982), digested by the regular Kjeldahl method, p. 610, and analyzed by the indophenol blue method, p. 674 |
| Total nitrogen | Sum of $NO_2$-N and total Kjeldahl-N; assuming $NO_2$-N is minimal |
| Citric acid soluble phosphorus | *Methods of Analysis of the Association of Official Analytical Chemists* (Horwitz, 1980), p. 13 |
| Bray P-l | *Methods of Soil Analysis* (Page, 1982), phosphorus soluble in dilute acid-fluoride, p. 416 |
| Total phosphorus | Weighed dried soil is digested with sulfuric/nitric acid mixture and then analyzed according to *Standard Methods* (1985), digested by $H_2SO_4 + HNO_3$, Sec 424 C - II, and analyzed by ascorbic acid method, Sec. 424 F |
| Boron, B | *Methods of Soil Analysis* (Page, 1982), extracted by hot water, p. 443, and analyzed by the azomethine-H method, p. 435 |
| Heavy metals | Extracted with HC1 and $HNO_3$ and then analyzed by atomic absorption |
| Particle size | Sieve-pipet method, by Guy (1969); particles greater than 0.062 mm in size are sand, 0.062 - 0.004 mm are silt, less than 0.004 mm are clay |

# RESULTS AND DISCUSSION

## Background Information

The characteristics of alum sludge and composited soil samples collected in both corn and soybean plots prior to sludge application are shown in table 4. Characteristics of sewage sludge from the Greater Peoria Sanitary District are also included for reference. Generally, most of the soil properties for both test plots are comparable except for higher nitrogen and total phosphorus concentrations in the corn plots and higher manganese in the soybean plots.

A comparison of the characteristics of alum sludge and soil samples, as indicated in table 4, shows that there were higher pH levels and higher concentrations of organic matter, percent moisture, CEC, all forms of nitrogen, total phosphorus, potassium, boron, aluminum, iron, calcium, magnesium, manganese, and other heavy metals in the sludge. Only Bray P-1 available phosphorus and percent total solids were found to be greater in soils than in alum sludge. In other words, the fertility values of alum sludge, based on the major nutrients and micronutrients, are higher than those of the soils at Monmouth except with regard to Bray P-l plant-available soil phosphorus.

The CCE test is often used to evaluate the effect of the impurities of agricultural lime. This test involves titrating a sample with an acid until a neutral pH is obtained. An equivalent amount of pure calcium carbonate is then titrated with the acid. Any reduction in acid required for neutralization of the sample is assumed to be a result of the impurities.

The alum sludge from the Peoria waterworks, which was applied to the test plots, had a CCE value of 12.5 percent (table 4). CCE levels for lime-softening sludge from the Champaign-Urbana water treatment plant were between 92 and 95 percent (Russell, 1980). CCE values for agricultural limestone in east-central Illinois typically range from 87 to 91 percent. These values are well above 80 percent, which is generally considered a minimum acceptable value.

The 1986 and 1987 daily precipitation data listed in Appendices A1 and A2 were provided by the Northwestern Agricultural Research and Demonstration Center of the University of Illinois. No soil moisture shortage occurred during the crop growing period.

Monthly 1986 and 1987 weather data are shown in Appendix B for the ranges in air temperature, relative humidity, soil temperature, and precipitation. These data were also obtained from the Research and Demonstration Center.

## Effects on Soil Properties

Results of physical and chemical analyses of soils in the test plots are listed in Appendices C1 through C29. The effects of alum sludge application on the parameters measured in soils, based on the averages of three replicates, are shown in tables 5 through 33.

### *Total Solids*

The percentage of total solids (TS) in soils was tested four times per year for each corn and soybean plot. The average TS ranged from 76.0 to 83.5 percent for the corn plots and from 78.2 to 83.8 percent for the soybean plots (table 5).

Table 5 shows no significant differences among the four alum sludge treatment rates, except for the soybean plots on September 4, 1987. On this date, the percentages of TS in the 2.5 and 10 t/a soybean plots were significantly greater than that in the 20 t/a soybean plots. (The difference between the two means was larger than 1.4). However, there were no statistical differences between each of the sludge-treated plots and the control plots.

### *Organic Matter*

As shown in table 6, alum sludge application did not affect the percent of organic matter in the corn plots during the two-year study or in the soybean plots in 1987. However, on May 21, 1986, the percent organic matter in the soybean control plots was significantly higher than that in the 10 and 20 t/a test plots. Also on July 18, 1986, significant differences in organic matter were observed between the 2.5 and 10 t/a plots and between the 2.5 and 20 t/a plots, although no significant difference was observed between the control and any sludge-treated plots. There was no significant effect observed for August 29 or October 21, 1986, or for any 1987 samples as a result of sludge applications. One can conclude that the 1986 alum sludge application had no impact on the organic matter content of soybean plots.

### *Moisture Content*

As indicated in table 7, on September 4, 1987, the percent of moisture content in soils in the 20 t/a soybean plots was significantly higher than that in either the 2.5 t/a or 10 t/a plots. However, the soil

## Table 4. Characteristics of Alum Sludge and Test Plot Soils Prior to Sludge Application, April 22, 1986

| *Parameters* | *Alum sludge* | *Corn plots* | *Soybean plots* | *GPSD* sewage sludge* |
|---|---|---|---|---|
| Total solids, % | 70.3 | 79.5 | 80.1 | 63.6 |
| Organic matter, % | 14.4 | 5.3 | 7.0 | 10.5 (VS)† |
| Moisture content, % | 29.7 | 20.5 | 19.9 | |
| Bulk density, g/cc‡ | 1.97 | 2.01 | 2.06 | |
| pH | 8.08 | 5.37 | 5.39 | 7.8 |
| Soil acidity, meq/100 g | | 0.22 | 0.11 | |
| Calcium carbonate equivalent (CCE), % | 12.5 | 0 | 0 | |
| Cation exchange capacity (CEC), meq/100 g | 17.8 | 13.9 | 14.0 | |
| Ammonia-nitrogen ($NH_3$-N), mg/kg | 297 | 229 | 157 | 500 |
| Nitrate-nitrogen ($NO_3$-N), mg/kg | 15.1 | 8.9 | 4.5 | 200 |
| Total Kjeldahl-nitrogen, mg/kg | 4423 | 2262 | 1642 | 6800 |
| Total nitrogen, mg/kg | 4735 | 2500 | 1804 | 7000 |
| Citric acid soluble phosphorus, mg/kg | 3543.8 | | | |
| Bray P-1, mg/kg | 3.6 | 21 | 20 | |
| Total phosphorus, mg/kg | 3544 | 698 | 584 | 27,900 ($P_2O_5$) |
| Potassium (K), % | 0.104 | 0.058 | 0.070 | 0.37 ($K_2O$) |
| Aluminum (A1), total, % | 2.78 | 0.99 | 1.12 | 2.35 |
| Boron, mg/kg | 0.7 | 0.5 | 0.3 | |
| Cadmium (Cd), mg/kg | 1.9 | <1.0 | <1.0 | 11 |
| Calcium (Ca), % | 4.936 | 0.313 | 0.283 | |
| Chromium (Cr), mg/kg | 53 | 15 | 17 | 220 |
| Copper (Cu), mg/kg | 35 | 10 | 13 | 469 |
| Iron (Fe), total, % | 2.08 | 1.55 | 1.18 | 0.24 |
| Lead (Pb), mg/kg | 62 | 16 | 11 | 129 |
| Magnesium (Mg), % | 0.759 | 0.170 | 0.245 | |
| Manganese (Mn), mg/kg | 830 | 520 | 680 | 518 |
| Nickel (Ni), mg/kg | 60 | 26 | 35 | 62 |
| Zinc (Zn), mg/kg | 160 | 38 | 43 | 310 |
| Particle size distribution, % | | | | |
| Sand | | 60.4 | 2.3 | 1.3 |
| Silt | | 23.0 | 76.9 | 68.1 |
| Clay | | 16.6 | 20.8 | 30.6 |

*GPSD = Greater Peoria Sanitary District (data from Garcia et al., 1981)
† VS = volatile solids, %
‡ Samples were inadvertently compacted

**Table 5. Effect of Alum Sludge Application on Total Solids (%) in Soils**

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 81.0 | 79.9 | 77.9 | 77.0 | 79.7 | 82.5 | 79.9 | 81.3 |
| 2.5 | 80.5 | 79.9 | 77.9 | 76.9 | 79.6 | 83.1 | 80.4 | 81.6 |
| 10 | 80.6 | 80.4 | 77.9 | 77.0 | 80.7 | 83.0 | 81.5 | 82.9 |
| 20 | 79.7 | 79.3 | 77.0 | 76.0 | 80.9 | 83.5 | 81.4 | 82.8 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 79.4 | 81.5 | 80.0 | 79.5 | 78.9 | 83.8 | 80.3 | 80.7 |
| 2.5 | 79.9 | 81.0 | 79.9 | 79.1 | 78.7 | 83.5 | 81.2 | 80.7 |
| 10 | 80.1 | 81.8 | 81.7 | 80.7 | 78.6 | 83.3 | 81.4 | 81.1 |
| 20 | 80.1 | 82.2 | 81.2 | 80.8 | 78.2 | 82.5 | 79.3 | 79.9 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 1.4 | NS |

**Table 6. Effect of Alum Sludge Application on Organic Matter (%) in Soils**

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 6.4 | 6.2 | 6.3 | 6.7 | 4.8 | 5.1 | 5.1 | 5.3 |
| 2.5 | 6.8 | 6.6 | 6.9 | 6.8 | 5.3 | 5.8 | 5.5 | 5.9 |
| 10 | 6.6 | 6.5 | 6.8 | 6.6 | 3.8 | 4.3 | 5.0 | 4.2 |
| 20 | 6.9 | 8.0 | 7.1 | 7.1 | 4.0 | 4.1 | 3.9 | 4.2 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 5.8 | 5.2 | 5.2 | 5.4 | 6.4 | 6.9 | 6.5 | 6.4 |
| 2.5 | 5.3 | 6.3 | 5.8 | 5.8 | 6.8 | 7.1 | 6.7 | 6.8 |
| 10 | 3.7 | 4.2 | 4.2 | 4.3 | 6.6 | 6.9 | 6.7 | 6.4 |
| 20 | 4.0 | 3.7 | 4.2 | 4.4 | 7.0 | 7.2 | 7.3 | 6.9 |
| LSD 10% | 1.0 | 1.6 | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

**Table 7. Effect of Alum Sludge Application on Moisture Content (%) in Soils**

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 19.0 | 20.1 | 22.1 | 23.0 | 20.3 | 17.4 | 20.1 | 18.7 |
| 2.5 | 19.5 | 20.1 | 22.1 | 23.1 | 20.4 | 16.9 | 19.6 | 18.4 |
| 10 | 19.4 | 19.6 | 22.1 | 23.0 | 19.3 | 17.0 | 18.5 | 17.1 |
| 20 | 20.3 | 20.7 | 23.0 | 24.0 | 19.1 | 16.5 | 18.6 | 17.2 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 20.6 | 18.5 | 20.0 | 20.5 | 21.1 | 16.2 | 19.7 | 19.3 |
| 2.5 | 20.1 | 19.0 | 20.1 | 20.9 | 21.3 | 16.5 | 18.8 | 19.2 |
| 10 | 19.9 | 18.2 | 18.3 | 19.3 | 21.4 | 16.7 | 18.6 | 18.9 |
| 20 | 19.9 | 17.8 | 18.8 | 19.2 | 21.8 | 17.5 | 20.7 | 20.1 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 1.4 | NS |

*Note: LSD = least significant difference; NS = no significant difference*

moisture content in the control plots was not significantly different from that in any of the sludge application plots.

For the other samples, table 7 suggests that alum sludge application has no effect on the percent moisture in soils for growing either corn or soybeans. Nevertheless, Bugbee and Frink (1985) reported that the media aeration and moisture-holding capacity of potting soil were significantly improved by the addition of alum sludge.

### *Bulk Density*

Some statistical differences were observed in bulk densities (table 8). In the corn plots, on October 21, 1986, bulk density in the 10 t/a plots was significantly greater than that in the control plots; also, on August 21, 1987, bulk density in the 2.5 t/a plots was significantly less than that in the control, 10 t/a, and 20 t/a plots.

For the soybean plots, on July 18, 1986, bulk density in the 10 t/a plots was significantly higher than that in the soybean control plots; also bulk density in both the 10 t/a and 20 t/a plots was significantly greater than that in the 2.5 t/a plots. On July 17, 1987, in the soybean plots, bulk density in the control and 20 t/a plots was significantly greater than that in the 2.5 t/a plots.

The above results indicate that the differences in bulk densities were inconsistent and occurred once each year for each crop. It cannot be concluded that alum application has any impact on soil bulk density. Similarly, Bugbee and Frink (1985) reported that bulk density was not different among different alum sludge applications to potting soil.

### *pH*

Since the average value of the pH is meaningless, the pH values obtained were not statistically evaluated. The median pH values are presented in table 9. Inspection of Appendix C5 shows that overall pH ranged from 4.86 to 7.63. In general, soil pH values increased with higher sludge application rates because of the higher alum sludge pH. This is a beneficial effect of sludge application.

### *Acidity*

Table 10 indicates that there was no impact on soil acidity in the two years after 1986 alum sludge application.

## Table 8. Effect of Alum Sludge Application on Bulk Density (g/cc) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24* | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 2.06 | 1.52 | 1.34 | 1.22 | 1.40 | 1.52 | 1.43 | 1.48 |
| 2.5 | 2.03 | 1.64 | 1.23 | 1.25 | 1.41 | 1.22 | 1.21 | 1.34 |
| 10 | 2.06 | 1.67 | 1.30 | 1.32 | 1.51 | 1.47 | 1.46 | 1.40 |
| 20 | 2.05 | 1.69 | 1.26 | 1.16 | 1.50 | 1.50 | 1.56 | 1.44 |
| LSD 10% | NS | NS | NS | 0.08 | NS | NS | 0.16 | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21* | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1.81 | 1.50 | 1.43 | 1.37 | 1.48 | 1.31 | 1.25 | 1.26 |
| 2.5 | 1.89 | 1.38 | 1.42 | 1.41 | 1.42 | 1.20 | 1.34 | 1.31 |
| 10 | 1.92 | 1.75 | 1.49 | 1.48 | 1.41 | 1.30 | 1.33 | 1.34 |
| 20 | 1.95 | 1.69 | 1.44 | 1.44 | 1.31 | 1.39 | 1.29 | 1.25 |
| LSD 10% | NS | 0.24 | NS | NS | NS | 1.1 | NS | NS |

**Samples collected on 4/24/86 and 5/21/86 were inadvertently compacted.*

*Note: LSD = least significant difference; NS = no significant difference*

## Table 9. Effect of Alum Sludge Application on pH (median) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 5.07 | 5.21 | 5.17 | 5.20 | 5.63 | 5.03 | 5.31 | 5.30 |
| 2.5 | 5.31 | 5.26 | 5.11 | 5.22 | 5.61 | 5.17 | 6.42 | 5.41 |
| 10 | 5.37 | 5.03 | 5.63 | 5.37 | 6.51 | 5.77 | 6.18 | 6.34 |
| 20 | 5.52 | 5.23 | 5.54 | 5.73 | 6.75 | 6.15 | 6.52 | 6.61 |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 5.30 | 5.35 | 5.26 | 5.52 | 5.05 | 5.09 | 5.20 | 5.00 |
| 2.5 | 5.64 | 5.67 | 5.75 | 5.85 | 5.17 | 5.06 | 5.38 | 4.99 |
| 10 | 5.82 | 5.81 | 6.25 | 6.15 | 5.41 | 5.40 | 5.55 | 5.33 |
| 20 | 6.10 | 5.99 | 6.63 | 6.36 | 6.00 | 5.82 | 6.03 | 5.58 |

*Note: The pH values obtained were not statistically evaluated.*

**Table 10. Effect of Alum Sludge Application on Acidity (meq/100 g) in Soils**

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.26 | 0.33 | 0.35 | 0.39 | 1.27 | 1.57 | 2.00 | 1.57 |
| 2.5 | 0.27 | 0.28 | 0.27 | 0.33 | 0.40 | 0.80 | 1.00 | 1.10 |
| 10 | 0.25 | 0.26 | 0.28 | 0.21 | 0.23 | 0.77 | 0.63 | 0.63 |
| 20 | 0.19 | 0.30 | 0.18 | 0.16 | 0.27 | 0.23 | 0.40 | 0.63 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.33 | 0.29 | 0.36 | 0.36 | 0.22 | 0.26 | 0.16 | 0.24 |
| 2.5 | 0.13 | 0.17 | 0.15 | 0.10 | 0.14 | 0.10 | 0.19 | 0.12 |
| 10 | 0.17 | 0.14 | 0.14 | 0.11 | 0.10 | 0.12 | 0.07 | 0.20 |
| 20 | 0.17 | 0.13 | 0.14 | 0.10 | 0.67 | 0.09 | 0.09 | 0.06 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

### Ammonia-Nitrogen

Inspection of table 11 shows that in the soybean plots, on August 29, 1986, ammonia-nitrogen concentrations in the 2.5 t/a plots were significantly greater than those in either the 10 or 20 t/a plots. On April 28, 1987, ammonia-nitrogen concentrations in the three sludge-treated plots were found to be higher than that in the soybean control plots. In fact, the alum sludge application had a positive effect in increasing ammonia-nitrogen content.

No effect was observed for sludge application in the corn plots for the two years. In general, one can conclude that alum sludge application did not affect ammonia-nitrogen in soil.

### Nitrate-Nitrogen

Table 12 shows that on August 13, 1986, the nitrate-nitrogen in both the 10 and 20 t/a corn plots was significantly less than that in the control plots. In contrast, on October 21, 1986, the nitrate-nitrogen in the 10 t/a corn plots was significantly higher than that in the control plots. On October 15, 1987, the nitrate-nitrogen in the 2.5 t/a corn plots was greater than that in the 0, 10, and 20 t/a plots. The observed differences in nitrate-nitrogen were not consistent.

In the soybean plots, sludge application had no effect except on two occasions (table 12). On July 17, 1987, nitrate-nitrogen in both the 10 and 20 t/a plots was significantly greater than that in the control plots. On September 4, 1987, nitrate-nitrogen in the 0, 10, and 20 t/a plots was greater than that in the 2.5 t/a plots. Overall, one can still conclude that nitrate-nitrogen was not changed by alum sludge application for either crop.

### Kjeldahl- and Total Nitrogen

It can be seen from tables 13 and 14 that on August 21, 1987, Kjeldahl-nitrogen and total nitrogen were significantly higher in the 2.5 t/a plots than in the 10 and 20 t/a plots, with no difference between treatment and control plots.

With the exception of August 21, 1987, no difference in Kjeldahl-nitrogen or total nitrogen was found during the two-year study. It is concluded that alum sludge application has no effect on Kjeldahl-nitrogen or total nitrogen in soil.

## Table 11. Effect of Alum Sludge Application on Ammonia-Nitrogen (mg/kg) in Soils

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *tla* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 188 | 164 | 172 | 152 | 178 | 155 | 130 | 126 |
| 2.5 | 261 | 160 | 190 | 162 | 163 | 202 | 160 | 156 |
| 10 | 274 | 171 | 190 | 160 | 124 | 112 | 96 | 91 |
| 20 | 201 | 183 | 197 | 184 | 107 | 115 | 100 | 86 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 107 | 113 | 105 | 115 | 138 | 278 | 194 | 201 |
| 2.5 | 122 | 168 | 122 | 141 | 158 | 254 | 215 | 212 |
| 10 | 65 | 91 | 72 | 81 | 167 | 266 | 228 | 197 |
| 20 | 72 | 68 | 72 | 72 | 164 | 273 | 221 | 224 |
| **LSD 10%** | **NS** | **NS** | **37** | **NS** | **16** | **NS** | **NS** | **NS** |

## Table 12. Effect of Alum Sludge Application on Nitrate-Nitrogen (mg/kg) in Soils

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 23.6 | 19.5 | 16.8 | 4.9 | 9.3 | 13.7 | 9.5 | 3.2 |
| 2.5 | 38.0 | 16.9 | 10.7 | 5.1 | 10.6 | 31.2 | 11.7 | 6.4 |
| 10 | 43.2 | 20.8 | 8.3 | 6.5 | 13.2 | 18.8 | 9.2 | 3.2 |
| 20 | 30.7 | 20.2 | 8.6 | 4.7 | 13.7 | 17.6 | 9.1 | 3.9 |
| LSD 10% | NS | NS | 8.2 | 1.2 | NS | NS | NS | 2.1 |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 3.0 | 3.0 | 2.3 | 3.2 | 6.3 | 5.7 | 6.8 | 6.5 |
| 2.5 | 2.4 | 3.5 | 3.0 | 3.7 | 5.4 | 6.4 | 5.0 | 5.6 |
| 10 | 2.0 | 2.0 | 2.7 | 3.7 | 5.6 | 7.3 | 7.3 | 5.9 |
| 20 | 1.9 | 2.6 | 2.7 | 3.5 | 5.7 | 6.9 | 6.7 | 5.6 |
| LSD 10% | NS | NS | NS | NS | NS | 0.9 | 1.1 | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 13. Effect of Alum Sludge Application on Total Kjeldahl-Nitrogen (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 6/13 | 8/13 | 10/21 | 1987 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 2240 | 2230 | 2260 | 2140 | 1590 | 1630 | 1270 | 1220 |
| 2.5 | 2440 | 2150 | 2340 | 2170 | 1350 | 1920 | 1550 | 1400 |
| 10 | 2370 | 2230 | 2210 | 2200 | 1010 | 1200 | 800 | 900 |
| 20 | 2340 | 2400 | 2370 | 2330 | 1070 | 1350 | 770 | 890 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 540 | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 7/18 | 8/29 | 10/21 | 1987 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1240 | 1530 | 1220 | 1460 | 2060 | 2400 | 1970 | 1960 |
| 2.5 | 1490 | 1930 | 1550 | 1640 | 2270 | 2440 | 2080 | 2040 |
| 10 | 1030 | 960 | 900 | 970 | 2030 | 2340 | 2140 | 1920 |
| 20 | 1050 | 1090 | 1000 | 1060 | 2200 | 2570 | 2200 | 2050 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

## Table 14. Effect of Alum Sludge Application on Total Nitrogen (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 6/13 | 8/13 | 10/21 | 1987 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 2260 | 2250 | 2280 | 2140 | 1600 | 1640 | 1280 | 1220 |
| 2.5 | 2480 | 2170 | 2350 | 2180 | 1360 | 1950 | 1560 | 1410 |
| 10 | 2410 | 2250 | 2220 | 2200 | 1030 | 1230 | 810 | 910 |
| 20 | 2370 | 2420 | 2380 | 2330 | 1080 | 1370 | 770 | 890 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 1110 | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 7/18 | 8/29 | 10/21 | 1987 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1240 | 1540 | 1230 | 1460 | 2070 | 2410 | 1980 | 2010 |
| 2.5 | 1490 | 1940 | 1550 | 1340 | 2270 | 2450 | 2090 | 2050 |
| 10 | 1030 | 970 | 900 | 980 | 2030 | 2380 | 2150 | 1930 |
| 20 | 1050 | 1090 | 1010 | 1060 | 2210 | 2580 | 2210 | 2060 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

### *Cation Exchange Capacity*

On August 13, 1986, average CEC in the 10 t/a plots was significantly less than that in the control, 2.5, and 20 t/a plots (table 15). Aside from this, table 15 shows that there was no difference in CEC between the treatment and the control plots. CEC was not affected by sludge application.

### *Bray P-1*

In the corn plots, on both June 13 and October 21, 1986, Bray P-l in both the 10 and 20 t/a plots was significantly higher than that in the control and 2.5 t/a plots (table 16). There is a beneficial effect of increased plant-available Bray P-l with alum sludge application as a result of the high total phosphorus in the sludge (table 4).

Similarly, on September 4, 1987, in both the 10 and 20 t/a soybean plots, Bray P-l was statistically higher than that in the control or 2.5 t/a plots (table 16). Thus a few incidents of increased Bray P-l in soil after high alum sludge applications were documented; however, 13 of 16 comparisons showed no significant differences in Bray P-l resulting from sludge application. Thus it can be concluded that sludge application has no effect on Bray P-l.

In contrast, in their potting soil amendment study, Bugbee and Frink (1985) claimed that "phosphorus deficiencies caused by the addition of dried alum sludge cannot likely be overcome by doubling the initial phosphorus fertilization." Grabarek and Krug (1987) reported that alum sludge bound phosphorus, making it unavailable or slowly available to maple and hemlock plants.

### *Total Phosphorus*

As shown in table 17, for the June 13, 1986, soil tests, the average total phosphorus in the 20 t/a corn plots was significantly greater than that in the control, 2.5, and 10 t/a plots. On October 21, 1986, total phosphorus in the 20 t/a soybean plots was significantly less than that in the control and 2.5 t/a plots. On September 4, 1987, total phosphorus in the 20 t/a soybean plots was significantly greater than that in the control, 2.5 t/a, or 10 t/a soybean plots. The differences were inconsistent. It can be concluded that total phosphorus levels were not affected by the sludge amendments.

**Table 15. Effect of Alum Sludge Application on Cation Exchange Capacity (meq/100 g) in Soils**

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 14.4 | 20.2 | 18.7 | 18.4 | 18.3 | 17.6 | 22.8 | 23.9 |
| 2.5 | 14.4 | 20.1 | 20.4 | 17.7 | 18.3 | 18.2 | 20.3 | 27.2 |
| 10 | 13.3 | 19.8 | 16.6 | 17.1 | 17.0 | 19.8 | 22.6 | 23.4 |
| 20 | 13.3 | 21.6 | 19.7 | 19.1 | 17.5 | 20.6 | 23.8 | 29.8 |
| LSD 10% | NS | NS | 2.1 | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 15.2 | 18.9 | 18.6 | 17.3 | 17.2 | 23.1 | 25.0 | 23.1 |
| 2.5 | 15.5 | 20.0 | 18.5 | 17.7 | 18.7 | 21.7 | 19.2 | 22.7 |
| 10 | 14.1 | 17.7 | 17.8 | 16.0 | 18.6 | 20.1 | 21.6 | 21.3 |
| 20 | 15.1 | 18.2 | 17.6 | 17.0 | 19.9 | 24.1 | 21.1 | 28.2 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 16. Effect of Alum Sludge Application on Bray P-1 (mg/kg) in Soils

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 10 | 13 | 13 | 13 | 11 | 13 | 12 | 12 |
| 2.5 | 12 | 11 | 14 | 14 | 12 | 18 | 12 | 15 |
| 10 | 15 | 17 | 17 | 16 | 10 | 15 | 12 | 12 |
| 20 | 13 | 19 | 18 | 20 | 13 | 17 | 14 | 16 |
| LSD 10% | NS | 4 | NS | 3 | NS | NS | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 16 | 26 | 23 | 19 | 9.4 | 10.5 | 11.2 | 11.0 |
| 2.5 | 18 | 34 | 20 | 25 | 8.9 | 14.0 | 10.3 | 12.7 |
| 10 | 18 | 25 | 22 | 22 | 11.7 | 13.3 | 15.3 | 15.7 |
| 20 | 33 | 18 | 25 | 27 | 13.4 | 17.3 | 18.7 | 16.3 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 3.6 | NS |

## Table 17. Effect of Alum Sludge Application on Total Phosphorus (mg/kg) in Soils

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 566 | 661 | 635 | 641 | 514 | 537 | 690 | 555 |
| 2.5 | 497 | 593 | 593 | 524 | 591 | 590 | 671 | 597 |
| 10 | 495 | 616 | 563 | 569 | 500 | 550 | 595 | 521 |
| 20 | 643 | 805 | 703 | 706 | 508 | 506 | 588 | 506 |
| LSD 10% | NS | 103 | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 547 | 608 | 507 | 523 | 635 | 660 | 609 | 733 |
| 2.5 | 656 | 640 | 593 | 599 | 532 | 551 | 589 | 654 |
| 10 | 544 | 578 | 527 | 452 | 569 | 661 | 631 | 695 |
| 20 | 508 | 506 | 472 | 416 | 648 | 691 | 749 | 705 |
| LSD 10% | NS | NS | NS | 105 | NS | NS | 98 | NS |

*Note: LSD = least significant difference; NS = no significant difference*

One of the major concerns in the agricultural use of water plant sludge is that coagulation sludges contain high concentrations of aluminum and iron hydroxides, which strongly fix phosphorus and may result in phosphorus deficiencies in crops. The equilibrium phosphorus concentration (EPC) is defined as the amount of phosphorus immediately available to the plant roots. An EPC of 50 micrograms of phosphorus per liter (ug P/L) is typically considered favorable for plant growth.

Elliott et al. (1989) found that with 5 percent sludge addition to a silt loam and sand, the EPC reduced to less than 10 ug P/L from 150-250 ug P/L. A sludge addition of 1 to 2 percent caused the EPC levels to fall below 50 ug P/L. They recommended that 10 to 20 dry t/a be an upper limit on soil loading for crop production.

### Potassium

On August 21, 1987, the potassium in the 2.5 and 20 t/a corn plots was significantly higher than that in the control and 10 t/a plots (table 18). Also on May 21, 1986, potassium in the 2.5 t/a soybean plots was significantly greater than that in the plots that had the other three application rates. With these two exceptions, the average potassium levels in soils were not affected by sludge application for either crop.

### Total Aluminum

A difference in total aluminum concentrations was observed in the corn plots on three sampling dates (table 19). On April 24, 1986, the average soil aluminum in the 2.5 t/a corn plots was significantly higher than that in the control plots. For the August 13, 1986, samples, aluminum in the 2.5 t/a corn plots was statistically less than that in the control and 20 t/a plots. On October 21, 1986, each of the three types of sludge-amended corn plots had higher aluminum concentrations than the control corn plots. There were no differences in aluminum levels in the corn plots on June 13, 1986, or in the 1987 samples. Thus the differences in aluminum levels in the corn plots were inconsistent.

In the soybean plots, differences in aluminum were not significant for any of the eight sampling dates (table 19). It may be concluded that alum sludge application had no effect on soil aluminum concentrations.

**Table 18. Effect of Alum Sludge Application on Potassium (mg/kg) in Soils**

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 760 | 730 | 530 | 650 | 1000 | 1070 | 690 | 750 |
| 2.5 | 800 | 770 | 520 | 640 | 590 | 1000 | 760 | 800 |
| 10 | 780 | 800 | 520 | 650 | 860 | 840 | 690 | 800 |
| 20 | 820 | 690 | 560 | 650 | 1000 | 1160 | 740 | 750 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 30 | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 730 | 750 | 720 | 740 | 800 | 810 | 670 | 650 |
| 2.5 | 980 | 690 | 620 | 830 | 730 | 870 | 690 | 650 |
| 10 | 760 | 700 | 680 | 610 | 680 | 940 | 670 | 650 |
| 20 | 820 | 700 | 630 | 730 | 730 | 890 | 710 | 650 |
| LSD 10% | 110 | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

**Table 19. Effect of Alum Sludge Application on Total Aluminum (%) in Soils**

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.93 | 1.02 | 1.06 | 0.97 | 1.00 | 1.51 | 1.13 | 1.15 |
| 2.5 | 1.04 | 1.06 | 0.97 | 1.05 | 1.04 | 1.43 | 1.12 | 1.21 |
| 10 | 1.00 | 1.01 | 1.01 | 1.04 | 0.88 | 1.26 | 1.09 | 1.15 |
| 20 | 0.97 | 1.08 | 1.08 | 1.05 | 0.95 | 1.60 | 1.13 | 1.16 |
| LSD 10% | 0.07 | NS | 0.06 | 0.04 | NS | NS | NS | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.98 | 1.03 | 1.10 | 1.11 | 0.89 | 1.02 | 1.02 | 0.96 |
| 2.5 | 1.00 | 1.05 | 1.07 | 1.09 | 0.90 | 1.12 | 1.05 | 1.00 |
| 10 | 0.88 | 1.03 | 1.04 | 1.02 | 0.92 | 1.19 | 1.07 | 1.09 |
| 20 | 1.02 | 1.01 | 1.01 | 1.09 | 0.88 | 1.20 | 1.13 | 1.03 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

### *Boron*

Boron levels in the 10 t/a soybean plots were significantly greater than those in the control plots for the September 4, 1987, tests (table 20). On October 15, 1987, average boron levels were significantly higher in all plots to which sludge had been added than in the control plots. There was no difference for the other six sampling dates for soybean plots, and no difference for any of the sampling dates for corn plot samples.

### *Cadmium*

Statistical analyses were not performed for cadmium in all soil samples (averages were not determined) because the cadmium levels in many samples were below detectable levels. The average cadmium concentrations for some sampling dates are listed in table 21.

### *Calcium, Chromium, and Copper*

As shown in tables 22 through 24, calcium, chromium, and copper concentrations in soils were not affected by alum sludge applications to either corn or soybean plots. Chromium analyses inadvertently were not performed for any 1987 soil samples.

### *Total Iron*

It can be seen from table 25 that on August 13, 1986, total iron levels in all sludge-amended corn plots were significantly lower than in the control corn plots. However, there was no significant difference in iron levels between the control and treated plots for the other seven corn sampling dates or for any of the soybean tests.

### *Lead*

As table 26 indicates, lead concentrations in corn plots and in soybean plots (except on July 18, 1986) showed no significant difference with sludge applications. On July 18, 1986, lead levels in the 2.5 t/a soybean plots were significantly greater than those in the control plots, and lead levels in the 20 t/a soybean plots were significantly lower than those in the control, 2.5 t/a, and 10 t/a plots.

**Table 20. Effect of Alum Sludge Application on Boron (mg/kg) in Soils**

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *tla* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 0.32 | 0.41 | 0.35 | 0.44 | 0.43 | 0.20 | 0.24 | 0.31 |
| 2.5 | 0.27 | 0.48 | 0.39 | 0.36 | 0.46 | 0.20 | 0.25 | 0.33 |
| 10 | 0.29 | 0.49 | 0.41 | 0.36 | 0.35 | 0.20 | 0.22 | 0.34 |
| 20 | 0.29 | 0.42 | 0.42 | 0.37 | 0.31 | 0.27 | 0.22 | 0.29 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *tla* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | 0.43 | 0.37 | 0.33 | 0.30 | 0.87 | 0.30 | 0.36 | 0.32 |
| 2.5 | 0.30 | 0.37 | 0.30 | 0.23 | 0.86 | 0.32 | 0.45 | 0.38 |
| 10 | 0.33 | 0.27 | 0.33 | 0.17 | 0.65 | 0.29 | 0.53 | 0.42 |
| 20 | 0.30 | 0.23 | 0.23 | 0.10 | 0.54 | 0.29 | 0.45 | 0.39 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 0.10 | 0.05 |

**Table 21. Effect of Alum Sludge Application on Cadmium (mg/kg) in Soils**

*Corn plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *4/24* | *6/13* | *8/13* | *10/21* | *4/28* | *6/26* | *8/21* | *10/15* |
| 0 | 0.68 | - | - | 0.87 | 0.37 | - | 0.48 | 0.42 |
| 2.5 | - | - | 1.30 | 0.88 | 0.49 | 0.40 | 0.60 | 0.56 |
| 10 | - | - | - | - | 0.82 | 0.55 | 0.84 | 0.59 |
| 20 | - | - | - | 1.07 | 0.66 | 0.56 | 0.77 | 0.79 |
| LSD 10% | | | | | 0.26 | | NS | NS |

*Soybean plots*

| *Rate,* | *1986* | | | | *1987* | | | |
|---|---|---|---|---|---|---|---|---|
| *t/a* | *5/21* | *7/18* | *8/29* | *10/21* | *4/28* | *7/17* | *9/4* | *10/15* |
| 0 | - | 0.96 | 1.48 | 0.08 | 0.89 | 0.33 | 0.36 | 0.56 |
| 2.5 | 0.55 | - | 1.52 | - | 0.73 | 0.57 | 0.72 | 0.69 |
| 10 | 0.46 | - | 1.10 | - | 0.95 | 0.27 | 0.54 | 0.73 |
| 20 | - | - | 1.23 | - | 0.80 | 0.13 | 0.42 | 0.66 |
| LSD 10% | | | | | NS | 0.19 | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 22. Effect of Alum Sludge Application on Calcium (%) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.362 | 0.476 | 0.288 | 0.315 | 0.267 | 0.294 | 0.260 | 0.264 |
| 2.5 | 0.287 | 0.306 | 1.044 | 0.272 | 0.502 | 0.386 | 0.321 | 0.338 |
| 10 | 0.270 | 0.270 | 0.292 | 0.265 | 0.954 | 1.136 | 0.772 | 0.875 |
| 20 | 0.377 | 0.340 | 0.334 | 0.352 | 0.512 | 0.413 | 0.417 | 0.397 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.227 | 0.223 | 0.274 | 0.259 | 0.465 | 0.458 | 0.355 | 0.339 |
| 2.5 | 0.475 | 0.310 | 0.381 | 0.422 | 0.419 | 0.375 | 0.242 | 0.281 |
| 10 | 1.170 | 0.764 | 0.248 | 0.895 | 0.406 | 0.382 | 0.292 | 0.331 |
| 20 | 0.360 | 0.432 | 0.368 | 0.384 | 0.472 | 0.505 | 0.383 | 0.360 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

## Table 23. Effect of Alum Sludge Application on Chromium (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 15 | 17 | 17 | 15 | Did not analyze | | | |
| 2.5 | 17 | 17 | 17 | 16 | | | | |
| 10 | 17 | 16 | 15 | 16 | | | | |
| 20 | 16 | 17 | 16 | 14 | | | | |
| LSD 10% | NS | NS | NS | NS | | | | |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 17 | 17 | 18 | 17 | Did not analyze | | | |
| 2.5 | 18 | 17 | 17 | 15 | | | | |
| 10 | 18 | 19 | 18 | 16 | | | | |
| 20 | 17 | 18 | 18 | 17 | | | | |
| LSD 10% | NS | NS | NS | NS | | | | |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 24. Effect of Alum Sludge Application on Copper (mg/kg) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 12 | 13 | 23 | 12 | 15 | 23 | 18 | 17 |
| 2.5 | 14 | 12 | 16 | 13 | 14 | 19 | 17 | 16 |
| 10 | 13 | 11 | 14 | 12 | 15 | 22 | 19 | 18 |
| 20 | 11 | 12 | 15 | 11 | 15 | 24 | 19 | 19 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 14 | 16 | 15 | 14 | 13 | 19 | 15 | 14 |
| 2.5 | 14 | 14 | 14 | 13 | 13 | 19 | 16 | 15 |
| 10 | 14 | 17 | 14 | 14 | 13 | 23 | 15 | 15 |
| 20 | 16 | 15 | 14 | 14 | 12 | 21 | 15 | 15 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

## Table 25. Effect of Alum Sludge Application on Total Iron (%) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1.08 | 1.23 | 1.73 | 1.18 | 1.82 | 1.97 | 1.76 | 1.89 |
| 2.5 | 1.18 | 1.18 | 1.50 | 1.29 | 1.69 | 1.79 | 1.62 | 1.80 |
| 10 | 1.10 | 1.17 | 1.46 | 1.28 | 1.65 | 1.73 | 1.76 | 1.89 |
| 20 | 1.03 | 1.17 | 1.47 | 1.09 | 1.75 | 2.19 | 1.85 | 1.58 |
| LSD 10% | NS | NS | 0.13 | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1.36 | 1.45 | 1.79 | 1.65 | 1.57 | 1.71 | 1.53 | 1.50 |
| 2.5 | 1.40 | 1.30 | 1.64 | 1.42 | 1.55 | 1.61 | 1.57 | 1.33 |
| 10 | 1.36 | 1.58 | 1.70 | 1.66 | 1.58 | 1.78 | 1.39 | 1.51 |
| 20 | 1.44 | 1.58 | 1.54 | 1.80 | 1.46 | 1.71 | 1.44 | 1.36 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 26. Effect of Alum Sludge Application on Lead (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 17 | 14 | 12 | 20 | 17 | 22 | 15 | 18 |
| 2.5 | 17 | 18 | 13 | 19 | 15 | 19 | 17 | 17 |
| 10 | 19 | 16 | 15 | 17 | 18 | 19 | 16 | 19 |
| 20 | 17 | 17 | 16 | 19 | 16 | 19 | 17 | 18 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| Rate, tla | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 16 | 16 | 20 | 16 | 16 | 19 | 18 | 16 |
| 2.5 | 17 | 19 | 17 | 17 | 17 | 17 | 17 | 19 |
| 10 | 17 | 18 | 19 | 16 | 17 | 18 | 17 | 15 |
| 20 | 15 | 13 | 19 | 15 | 15 | 19 | 18 | 16 |
| LSD 10% | NS | 2 | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

### Magnesium

Table 27 shows that sludge amendment had no effect on magnesium levels in the test plots except on July 17, 1987. On this date, all sludge-amended soybean plots showed significant decreases in magnesium content.

### Manganese

As indicated in table 28, the manganese levels in both corn and soybean test soils generally showed no change with the application of sludge except on August 13, 1986. On that date, the average manganese concentration in the 20 t/a corn plots was significantly lower than that in the control plots.

### Nickel

It can be seen from table 29 that the average nickel concentrations were not statistically different in any of the test plots for either corn or soybeans. Thus one may conclude that alum sludge application had no effect on nickel levels in the test plot soils.

### Zinc

As shown in table 30, on August 13, 1986, the average zinc concentration in the corn control plots was significantly higher than that in any of the sludge-amended plots. However, in the corn plots on June 26, 1987, and in the soybean plots on July 17, 1987, zinc in the 20 t/a soils was significantly greater than that in the control, 2.5 t/a, and 10 t/a soils. On the other 13 occasions, alum sludge amendments had no effect on zinc concentrations in the test plot soils.

### Particle Size Distribution

Effects of alum sludge application on particle size distribution are summarized in tables 31 through 33. It can be seen from table 31 that in the 1986 study, sludge application had no effect on the percent of sand in soils for either crop. However, on June 26, 1987, the percent of sand (12.6 percent) in the corn control plots was significantly higher than the percent in the sludge-amended plots. This was due possibly to the nonhomogeneity of the soil in the

## Table 27. Effect of Alum Sludge Application on Magnesium (mg/kg) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 2220 | 2980 | 1880 | 1940 | 2730 | 2730 | 2090 | 1870 |
| 2.5 | 1560 | 1750 | 9140 | 1660 | 3550 | 2670 | 1940 | 1900 |
| 10 | 1740 | 1650 | 1630 | 1650 | 5640 | 5510 | 4880 | 6730 |
| 20 | 1820 | 1820 | 1740 | 1730 | 3800 | 3460 | 2410 | 2480 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 2230 | 2170 | 2240 | 2320 | 2520 | 2130 | 1660 | 1820 |
| 2.5 | 3320 | 2320 | 2840 | 2670 | 2060 | 1810 | 1120 | 1450 |
| 10 | 10280 | 6370 | 2190 | 5810 | 2100 | 1900 | 1230 | 1470 |
| 20 | 3050 | 3830 | 2920 | 2890 | 2000 | 1880 | 1340 | 1470 |
| LSD 10% | NS | NS | NS | NS | NS | 154 | NS | NS |

## Table 28. Effect of Alum Sludge Application on Manganese (mg/kg) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 600 | 600 | 690 | 550 | 610 | 730 | 830 | 900 |
| 2.5 | 590 | 570 | 580 | 580 | 600 | 660 | 830 | 860 |
| 10 | 570 | 530 | 570 | 600 | 600 | 700 | 880 | 840 |
| 20 | 480 | 540 | 490 | 530 | 610 | 760 | 880 | 870 |
| LSD 10% | NS | NS | 121 | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 600 | 610 | 640 | 640 | 530 | 770 | 810 | 850 |
| 2.5 | 650 | 630 | 620 | 610 | 810 | 620 | 790 | 700 |
| 10 | 580 | 620 | 600 | 600 | 570 | 600 | 780 | 720 |
| 20 | 640 | 610 | 620 | 640 | 560 | 600 | 760 | 660 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 29. Effect of Alum Sludge Application on Nickel (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 22 | 24 | 29 | 27 | 22 | 17 | 12 | 15 |
| 2.5 | 24 | 21 | 26 | 27 | 17 | 15 | 11 | 12 |
| 10 | 22 | 21 | 24 | 26 | 15 | 17 | 13 | 14 |
| 20 | 22 | 23 | 25 | 25 | 17 | 19 | 14 | 13 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 29 | 33 | 33 | 8 | 13 | 10 | 11 |
| 2.5 | 30 | 26 | 30 | 30 | 11 | 13 | 10 | 11 |
| 10 | 31 | 32 | 32 | 31 | 10 | 13 | 9 | 12 |
| 20 | 33 | 30 | 31 | 31 | 7 | 13 | 9 | 11 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

## Table 30. Effect of Alum Sludge Application on Zinc (mg/kg) in Soils

*Corn plots*

| Rate, t/a | 1986 4/24 | 1986 6/13 | 1986 8/13 | 1986 10/21 | 1987 4/28 | 1987 6/26 | 1987 8/21 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 38 | 39 | 43 | 40 | 42 | 57 | 39 | 46 |
| 2.5 | 37 | 36 | 39 | 40 | 41 | 57 | 42 | 46 |
| 10 | 40 | 37 | 39 | 40 | 43 | 55 | 43 | 48 |
| 20 | 37 | 38 | 39 | 39 | 42 | 80 | 45 | 49 |
| LSD 10% | NS | NS | 2 | NS | NS | 17 | NS | NS |

*Soybean plots*

| Rate, t/a | 1986 5/21 | 1986 7/18 | 1986 8/29 | 1986 10/21 | 1987 4/28 | 1987 7/17 | 1987 9/4 | 1987 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 39 | 41 | 40 | 43 | 42 | 51 | 43 | 44 |
| 2.5 | 42 | 37 | 37 | 39 | 40 | 52 | 43 | 43 |
| 10 | 39 | 43 | 41 | 42 | 42 | 56 | 45 | 48 |
| 20 | 45 | 40 | 39 | 43 | 40 | 62 | 46 | 45 |
| LSD 10% | NS | NS | NS | NS | NS | 6 | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

## Table 31. Effect of Alum Sludge Application on Particle Size Distribution (% Sand) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 3.7 | 2.7 | 1.3 | 2.0 | 1.4 | 12.6 | 6.4 | 3.9 |
| 2.5 | 4.2 | 2.4 | 1.7 | 2.5 | 1.5 | 4.7 | 7.0 | 3.7 |
| 10 | 2.3 | 2.5 | 1.9 | 2.5 | 2.2 | 5.8 | 6.2 | 2.9 |
| 20 | 3.9 | 3.5 | 2.1 | 2.8 | 3.5 | 4.0 | 5.1 | 3.0 |
| LSD 10% | NS | NS | NS | NS | NS | 4.3 | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1.6 | 2.2 | 1.1 | 0.8 | 2.0 | 9.2 | 5.0 | 5.3 |
| 2.5 | 1.9 | 2.1 | 1.8 | 1.4 | 2.6 | 5.3 | 6.2 | 6.0 |
| 10 | 1.6 | 1.6 | 2.0 | 1.5 | 2.5 | 6.2 | 5.8 | 4.9 |
| 20 | 1.5 | 1.5 | 1.6 | 1.9 | 2.0 | 4.8 | 5.1 | 5.5 |
| LSD 10% | NS | NS | NS | NS | 0.45 | NS | NS | NS |

## Table 32. Effect of Alum Sludge Application on Particle Size Distribution (% Silt) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 67.7 | 70.7 | 68.0 | 66.1 | 69.8 | 62.6 | 70.5 | 67.8 |
| 2.5 | 68.6 | 68.2 | 67.4 | 62.7 | 72.1 | 73.0 | 69.6 | 69.9 |
| 10 | 69.8 | 70.5 | 68.0 | 65.6 | 79.6 | 67.7 | 69.1 | 68.6 |
| 20 | 69.3 | 70.3 | 67.0 | 64.7 | 71.3 | 69.5 | 65.8 | 67.8 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 64.8 | 68.3 | 65.5 | 65.2 | 69.1 | 76.2 | 73.8 | 70.1 |
| 2.5 | 66.9 | 70.2 | 68.2 | 66.5 | 68.7 | 78.0 | 65.4 | 69.5 |
| 10 | 67.5 | 70.1 | 66.6 | 72.8 | 68.8 | 76.7 | 72.2 | 71.8 |
| 20 | 67.3 | 66.3 | 67.6 | 64.6 | 72.5 | 78.5 | 71.0 | 69.2 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

Table 33. Effect **of Alum** Sludge **Application** on Particle Size Distribution (% Clay) in Soils

*Corn plots*

| *Rate, t/a* | *1986* 4/24 | 6/13 | 8/13 | 10/21 | *1987* 4/28 | 6/26 | 8/21 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 28.6 | 26.5 | 30.8 | 31.9 | 28.8 | 24.7 | 23.1 | 28.3 |
| 2.5 | 27.2 | 29.3 | 30.9 | 34.8 | 26.4 | 22.2 | 23.3 | 26.3 |
| 10 | 27.9 | 27.0 | 30.1 | 31.9 | 18.2 | 26.4 | 24.7 | 28.4 |
| 20 | 26.8 | 26.2 | 31.0 | 32.5 | 25.2 | 26.6 | 29.1 | 29.2 |
| LSD 10% | NS | NS | NS | 1.8 | NS | NS | NS | NS |

*Soybean plots*

| *Rate, t/a* | *1986* 5/21 | 7/18 | 8/29 | 10/21 | *1987* 4/28 | 7/17 | 9/4 | 10/15 |
|---|---|---|---|---|---|---|---|---|
| 0 | 33.6 | 29.6 | 33.4 | 33.9 | 28.9 | 14.6 | 21.3 | 24.6 |
| 2.5 | 31.2 | 27.7 | 30.4 | 32.1 | 28.7 | 16.6 | 28.4 | 24.5 |
| 10 | 30.9 | 28.3 | 31.4 | 25.7 | 28.7 | 17.2 | 22.0 | 23.2 |
| 20 | 31.2 | 32.2 | 30.8 | 33.5 | 25.4 | 16.7 | 23.8 | 25.3 |
| LSD 10% | NS | NS | NS | NS | NS | NS | 3.0 | NS |

*Note: LSD = least significant difference; NS = no significant difference*

test plots or possibly to analytical errors. On April 28, 1987, the percentage of sand in both the soybean control plots and the 20 t/a plots was lower than that in the 2.5 t/a and 10 t/a plots.

As indicated in table 32, the percent of silt in the soil in corn and soybean plots was not affected by the addition of alum sludge. Inspection of table 33 shows that on October 21, 1986, for corn plots and on September 4, 1987, for soybean plots, the percent of clay in the 2.5 t/a plots was significantly higher than that in the control, 10 t/a, or 20 t/a plots. However, no effect on percent clay was observed as a result of alum sludge application on the 14 other occasions (table 33). One may conclude that alum sludge applications on corn and soybean plots had no effect on soil particle distributions.

### *General Observations*

In the case of both corn and soybeans, soil test levels were usually not affected by the alum sludge applications. There were several differences between the treated and the control plots between sampling dates, which were due to the inherent differences in the soil characteristics of the test plots. It is impossible to have perfect uniformity among areas when working with soils. In a few very rare instances, the soil test results were changed drastically when a lump of sludge ended up in the sample. These instances were most noticeable for the calcium and magnesium levels (tables 22 and 27), although almost no statistical differences were found.

## Corn Yields and Plant Parameters

The data on corn yields and measured corn plant parameters are listed in Appendix D. The results of the statistical analyses of these data are summarized in table 34. It can be seen from this table that for the 1986 study, corn yields were found to be significantly lower in the 2.5 and 10 t/a plots than in the 0 and 20 t/a plots. The corn plant populations in the 2.5 and 10 t/a plots were less than those in the 0 and 20 t/a plots, but only the population in the 10 t/a plots was significantly lower than that in the 0 and 20 t/a plots.

The reason for the plant population difference was unclear; it was possibly related to the inherent soil characteristics. The plant populations in the plots with the highest sludge application rate were not affected by the sludge. Small differences in plant

**Table 34. Effect of Alum Sludge Application on Corn Yields and Plant Parameters**

| *Year of study* | | *Application rate, t/a* | *Corn yield, bu/a* | Grain *moisture,* % | *Test weight,* lb/bu | *Population, plants /a* |
|---|---|---|---|---|---|---|
| *1986* | | 0 | 221.01 | 15.9 | 54.1 | 25070 |
| | | 2.5 | 210.11 | 16.7 | 54.5 | 24390 |
| | | 10 | 203.65 | 16.7 | 55.0 | 23430 |
| | | 20 | 222.07 | 16.4 | 55.8 | 25070 |
| | LSD 10% | | 7.21 | NS | 1.0 | 1490 |
| *1987* | | 0 | 163.14 | 18.4 | | 19280 |
| | | 2.5 | 204.97 | 17.8 | | 22528 |
| | | 10 | 137.32 | 17.4 | | 14953 |
| | | 20 | 179.08 | 17.8 | | 17806 |
| | LSD 10% | | NS | 0.58 | | NS |

*Note: LSD = least significant difference; NS = no significant difference*

populations can cause significant yield differences in plots. The variability in plant populations and yield was probably caused by poor seedbed preparation and dry soil conditions, not by residual alum sludge.

In 1987, corn yields and corn plant populations were not found to be significantly different among all the test plots (table 34). Alum sludge applied in 1986 had no effect on corn yields or plant populations the following year.

A field study by Naylor et al. (1987) also showed that yields of corn grown on sludge-treated soil were not affected by application rates up to 20 t/a. Garcia et al. (1981) grew corn on strip-mined soil amended with anaerobically digested liquid sewage sludge at a rate of 25 t/a. They observed that growing corn of good quality on strip-mined soil is almost impossible. In contrast, other corn grown in soil to which sewage sludge had been added was well developed, and the corn yield was four times as great as that of corn from untreated fields.

For the 1986 study, table 34 suggests that corn test weights in plots with 2.5 and 10 t/a application rates were not significantly different from those in control plots (0 t/a), but test weights for the 20 t/a plots were significantly higher than for the control plots. The corn test weights were not measured in 1987.

Table 34 also indicates that corn grain moisture was not significantly affected by alum sludge application in 1986. However, in the 1987 study, the corn grain moisture in the control plots was found to be significantly higher than that in all sludge-treated plots.

## Soybean Yields and Plant Parameters

The raw data on soybean yields and soybean plant parameters are given in Appendix D. The statistical analyses are summarized in table 35. As shown in table 35, for both the 1986 and 1987 studies, soybean yields, soybean grain moisture, soybean plant height, and soybean plant populations were not significantly affected by alum sludge application. Some numerical differences were observed between the treatments, but they are not believed to have been caused by the sludge applications because similar variations were observed for the control plots.

## Corn Grain Analysis

In 1987, the grain samples of corn and soybeans were lost. The 1986 data from 16 grain analyses for corn and soybeans are listed in Appendix E. The

**Table 35. Effect of Alum Sludge Applications on Soybean Yields and Plant Parameters**

| *Year of study* | | *Application rate, t/a* | *Corn yield, bu/a* | *Grain moisture, %* | *Plant height, inches* | *Population, plants/a* |
|---|---|---|---|---|---|---|
| *1986* | | 0 | 40.27 | 13.1 | 36.0 | 136490 |
| | | 2.5 | 43.06 | 13.3 | 37.1 | 133000 |
| | | 10 | 40.69 | 13.2 | 36.3 | 128940 |
| | | 20 | 40.10 | 13.4 | 35.3 | 122550 |
| | LSD 10% | | NS | NS | NS | NS |
| *1987* | | 0 | 42.54 | 8.03 | 36.01 | 122500 |
| | | 2.5 | 39.71 | 8.00 | 35.03 | 120200 |
| | | 10 | 37.11 | 8.07 | 34.10 | 118800 |
| | | 20 | 41.64 | 8.33 | 36.33 | 117600 |
| | LSD 10% | | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

statistical analyses for grain are summarized in table 36. Inspection of table 36 shows that corn grain moisture in the 2.5 and 20 t/a plots was significantly higher than that in the 0 and 10 t/a plots. There were no significant differences in percent moisture between 0 and 10 t/a. Aluminum and cadmium levels in corn grain were not evaluated because some measurements were below the detectable limits.

The other 13 chemical parameters measured for corn grain showed no effects resulting from the alum sludge application (table 36). However, Garcia et al. (1981) reported a significant protein enhancement of 2.5 percent in the grain of corn grown in soil to which sewage sludge had been added.

## Soybean Grain Analysis

Table 36 indicates that 15 chemical parameters of soybean grain examined in 1986 were unresponsive to the alum sludge applications. Aluminum was not statistically evaluated. The data show that there were no heavy metals accumulations in the corn or soybeans from the sludge application (table 36). In fact, nickel levels in soybean grain from the treated plots were lower than the levels in grain from the control plots.

One of the major issues concerning application of water treatment plant sludge is that metals potentially can cause water pollution and contamination of food crops. The results of this study suggest that the uptake of metals in corn and soybean grains did not show an increase, and that there are no adverse effects of the sludge application.

## Corn Plant Tissue

Fourteen chemical analyses were performed on the whole plant samples (root not included) for each crop. The results are listed in Appendices F and G. The statistical analyses of these data are summarized in table 37.

As shown in table 37, none of the 14 parameters examined in 1986 in corn whole plant tissue were affected by the addition of alum sludge. Almost every heavy metal level was generally reduced instead of increased.

Nitrogen and phosphorus content in corn whole plant tissue was not determined during the 1987 study. The other 12 chemical parameters measured, with the exception of cadmium, showed no effect from alum sludge application. In fact, cadmium concentrations in the control corn plots were higher than those in the sludge-amended plots in 1987. However, cadmium concentrations in the control plots were only significantly greater than those in the 2.5 and 10 t/a plots.

**Table 36. Effect of Sludge Applications on Chemical and Physical Characteristics of Corn and Soybean Grains - 1986 Study**

| *Sludge rate, t/a* | *N* | *P* | *K* | *Ca* | *Mg* | *Mn* | *Zn* | *Fe* | *Cu* | *Al* | *Cd* | *Cr* | *Pb* | *Ni* | *Crude protein, %* | *Mois-ture, %* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *%* | | | | | | | *mg/kg* | | | | | | |
| *Corn grain* | | | | | | | | | | | | | | | | |
| 0 | 1.46 | 0.12 | 0.23 | 0.010 | 0.071 | 6.7 | 21 | 13 | 1.0 | <10 | 0.10 | 0.27 | 0.33 | 0.17 | 9.12 | 10.95 |
| 2.5 | 1.45 | 0.11 | 0.23 | 0.011 | 0.074 | 7.3 | 22 | 13 | 1.3 | <10 | 0.13 | 0.27 | 0.27 | 0.27 | 9.07 | 12.22 |
| 10 | 1.48 | 0.12 | 0.20 | 0.007 | 0.071 | 7.3 | 17 | 13 | 1.0 | <10 | >.1 | 0.20 | 0.33 | 0.13 | 9.23 | 11.05 |
| 20 | 1.43 | 0.11 | 0.22 | 0.009 | 0.073 | 7.7 | 15 | 14 | 1.3 | <10 | >.1 | 1.17 | 0.43 | 0.27 | 8.93 | 12.07 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS | NS | | | NS | NS | NS | NS | 0.79 |
| *Soybean grain* | | | | | | | | | | | | | | | | |
| 0 | 6.31 | 0.64 | 1.42 | 0.206 | 0.173 | 22 | 64 | 60 | 13 | <10 | 0.23 | 0.27 | 1.4 | 8.3 | 39.28 | 8.62 |
| 2.5 | 6.29 | 0.65 | 1.43 | 0.202 | 0.181 | 22 | 64 | 62 | 12 | <10 | 0.20 | 0.30 | 1.5 | 5.5 | 39.31 | 8.51 |
| 10 | 6.07 | 0.64 | 1.43 | 0.198 | 0.179 | 23 | 56 | 56 | 13 | <10 | 0.23 | 0.30 | 1.4 | 6.1 | 37.94 | 7.88 |
| 20 | 6.20 | 0.63 | 1.41 | 0.201 | 0.183 | 23 | 51 | 57 | 12 | <10 | 0.20 | 0.27 | 1.4 | 5.6 | 38.75 | 8.25 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS | NS | | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference*
*NS = no significant difference*

# Table 37. Effect of Sludge Applications on Chemical Characteristics of Whole Plants

| *Sludge rate, t/a* | *N* | *P* | *K* *%* | *Ca* | *Mg* | *Mn* | *Zn* | *Fe* | *Cu* | *Al* *mg/kg* | *Cd* | *Cr* | *Pb* | *Ni* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Corn -1986* | | | | | | | | | | | | | | |
| 0 | 0.79 | 0.07 | 0.683 | 0.372 | 0.224 | 82 | 73 | 673 | 5.0 | 164 | 0.23 | 1.1 | 7.4 | 1.2 |
| 2.5 | 0.75 | 0.06 | 0.657 | 0.376 | 0.226 | 79 | 59 | 590 | 4.7 | 189 | 0.23 | 1.0 | 3.9 | 1.1 |
| 10 | 0.76 | 0.06 | 0.537 | 0.385 | 0.226 | 78 | 49 | 550 | 5.0 | 158 | 0.23 | 0.9 | 3.8 | 1.0 |
| 20 | 0.73 | 0.06 | 0.530 | 0.359 | 0.214 | 62 | 54 | 587 | 5.3 | 138 | 0.27 | 0.9 | 3.6 | 1.0 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| *Corn -1987* | | | | | | | | | | | | | | |
| 0 | | | 0.43 | 0.374 | 0.285 | 35 | 7.9 | 267 | 4.2 | 177 | 0.10 | 0.49 | 1.3 | 1.3 |
| 2.5 | | | 0.33 | 0.381 | 0.287 | 25 | 7.8 | 244 | 3.8 | 171 | 0.05 | 0.43 | 1.4 | 1.2 |
| 10 | | | 0.40 | 0.428 | 0.331 | 31 | 8.0 | 298 | 4.5 | 237 | 0.05 | 0.60 | 1.5 | 1.6 |
| 20 | | | 0.36 | 0.393 | 0.318 | 29 | 6.3 | 351 | 4.5 | 241 | 0.07 | 0.51 | 1.7 | 1.5 |
| LSD 10 % | | | NS | NS | NS | NS | NS | NS | NS | NS | 0.03 | NS | NS | NS |
| *Soybeans - 1986* | | | | | | | | | | | | | | |
| 0 | 1.25 | 0.13 | 0.35 | 0.951 | 0.315 | 50 | 27 | 443 | 7.3 | 184 | 0.40 | 0.77 | 2.1 | 1.8 |
| 2.5 | 1.26 | 0.11 | 0.36 | 0.942 | 0.301 | 41 | 23 | 397 | 6.0 | 179 | 0.37 | 0.77 | 2.1 | 1.9 |
| 10 | 1.24 | 0.13 | 0.38 | 0.903 | 0.302 | 47 | 18 | 430 | 6.7 | 242 | 0.33 | 0.83 | 2.0 | 2.2 |
| 20 | 1.25 | 0.12 | 0.37 | 0.825 | 0.268 | 38 | 35 | 423 | 6.7 | 189 | 0.33 | 0.93 | 2.0 | 1.5 |
| LSD 10% | NS | NS | NS | 0.050 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| *Soybeans - 1987* | | | | | | | | | | | | | | |
| 0 | | | 0.75 | 0.984 | 0.538 | 16 | 8.8 | 67 | 7.3 | 32 | 0.40 | 0.14 | 2.1 | 2.0 |
| 2.5 | | | 0.71 | 1.048 | 0.563 | 16 | 9.3 | 79 | 8.0 | 45 | 0.40 | 0.14 | 2.0 | 1.9 |
| 10 | | | 0.75 | 1.062 | 0.567 | 16 | 10.2 | 101 | 8.0 | 56 | 0.35 | 0.15 | 2.3 | 1.9 |
| 20 | | | 0.77 | 1.095 | 0.518 | 14 | 8.1 | 88 | 6.8 | 48 | 0.39 | 0.25 | 2.0 | 1.8 |
| LSD 10 % | | | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

A field study by Kelling et al. (1977) showed that sewage sludge application to soil generally increased concentrations of Cu, Zn, Cd, and Ni in the vegetative corn tissue, but, except for Zn, incremental additions of sewage sludge had relatively little effect on the metal content of the corn grain. Garcia et al. (1979) found that concentrations of seven heavy metals (Zn, Mn, Ca, Pb, Cr, Cd, and Hg) increased in corn grain, cobs, and husks in that order.

## Soybean Plant Tissue

As with the corn plant tissue analyses, the soybean tissue analyses for the two-year study generally showed no effects from the addition of alum sludge except for one difference in calcium concentrations in 1986 (table 37). Average calcium concentrations in soybean plant tissues at the 20 t/a rate were significantly lower than those for the 0, 2.5, and 10 t/a plots. Inspection of table 37 shows that heavy metals did not accumulate in the soybean plant tissues after the addition of alum sludge.

## Corn and Soybean Leaf Tissue

The results from chemical analyses of corn and soybean leaf tissue are given in Appendices H and I. The statistical analyses are summarized in table 38. Nitrogen and phosphorus concentrations were determined only for 1986 corn leaf tissues. As shown in table 38, 13 parameters determined for corn leaf tissues showed no differences with or without alum sludge addition. However, for the 1986 study, average cadmium in the corn leaves in the 20 t/a plots was significantly higher than in the 0, 2.5, and 10 t/a plots. No statistical difference in cadmium content in corn leaves was observed during the 1987 study.

Only eleven chemical analyses were performed for soybean leaf tissues in 1986, and 12 analyses were carried out in 1987. Chromium was the only parameter that showed an effect from the alum sludge applications (table 38). In 1986, the average chromium concentration in the soybean leaves from the 20 t/a plots was significantly less than in those from the 0, 2.5, and 10 t/a plots.

In contrast, in the 1987 study, the chromium concentration in the soybean leaves from the 20 t/a plots was significantly greater than that in leaves from the other plots. Iron levels in soybean leaves in sludge-amended plots generally increased from the levels in the control plots, although the differences were not statistically significant (table 38).

The suggested critical nutrient levels for Illinois are presented in table 39 (University of Illinois, 1987). Lower concentrations may indicate a nutrient deficiency. A comparison of tables 38 and 39 shows that nitrogen and potassium levels in the corn plots were lower than the recommended critical nutrient levels. However, this was probably not caused by alum sludge application. There were no nutrient deficiencies observed in the soybean leaf tissues. Calcium, magnesium, manganese, zinc, iron, and copper in leaves were found to be higher than the recommended levels.

A comparison of heavy metals in corn grain, whole plants, and leaves (tables 36 through 38) shows that the highest metal levels occurred in the corn plant and leaves and the lowest in the grain. Similarly, Garcia et al. (1981) studied translocation of heavy metals (Zn, Mn, Cu, Pb, Cr, Cd, and Hg) in corn plants grown on strip-mined soil amended with anaero-bically digested sewage sludge. Their analysis of differential metal accumulation rates in seven tissues showed that the highest metal levels generally were observed in the corn leaves and roots and the lowest in the grain and cob.

# Table 38. Effect of Sludge Applications on Chemical Characteristics of Leaves

| *Sludge rate, t/a* | *N* | *P* | *K* % | *Ca* | *Mg* | *Mn* | *Zn* | *Fe* | *Cu* | *Al* mg /kg | *Cd* | *Cr* | *Pb* | *Ni* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Corn -1986* | | | | | | | | | | | | | | |
| 0 | 2.75 | 0.35 | 1.70 | 0.630 | 0.328 | 117 | 43 | 223 | 11 | 31 | 0.33 | 0.53 | 1.6 | 1.1 |
| 2.5 | 2.50 | 0.33 | 1.63 | 0.623 | 0.296 | 116 | 61 | 207 | 11 | 32 | 0.33 | 0.53 | 1.8 | 1.1 |
| 10 | 2.66 | 0.35 | 1.79 | 0.682 | 0.309 | 127 | 42 | 263 | 12 | 35 | 0.30 | 0.50 | 2.0 | 1.0 |
| 20 | 2.67 | 0.33 | 1.76 | 0.624 | 0.309 | 102 | 36 | 223 | 11 | 29 | 0.40 | 0.53 | 2.0 | 1.1 |
| LSD 10% | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.05 | NS | NS | NS |
| *Corn -1987* | | | | | | | | | | | | | | |
| 0 | | | 1.10 | 0.762 | 0.445 | 73 | 23 | 107 | 10 | 21 | 0.14 | 0.23 | 1.7 | 1.6 |
| 2.5 | | | 1.23 | 0.763 | 0.397 | 53 | 23 | 98 | 8 | 21 | 0.12 | 0.19 | 1.5 | 1.6 |
| 10 | | | 1.02 | 0.875 | 0.510 | 64 | 20 | 100 | 11 | 23 | 0.16 | 0.21 | 2.0 | 1.8 |
| 20 | | | 1.03 | 0.894 | 0.489 | 64 | 18 | 106 | 11 | 22 | 0.20 | 0.16 | 2.0 | 1.7 |
| LSD 10 % | | | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| *Soybeans - 1986* | | | | | | | | | | | | | | |
| 0 | | | 2.31 | 0.905 | 0.370 | | 68 | 190 | 10 | 23 | 0.47 | 0.77 | 2.3 | 9.6 |
| 2.5 | | | 2.39 | 0.917 | 0.331 | | 28 | 273 | 10 | 17 | 0.43 | 0.77 | 2.5 | 6.6 |
| 10 | | | 2.31 | 0.879 | 0.332 | | 36 | 223 | 11 | 20 | 0.47 | 0.77 | 2.3 | 8.8 |
| 20 | | | 2.17 | 0.789 | 0.315 | | 29 | 250 | 10 | 18 | 0.40 | 0.57 | 2.8 | 7.4 |
| LSD 10% | | | NS | NS | NS | | NS | NS | NS | NS | NS | 0.14 | NS | NS |
| *Soybeans - 1987* | | | | | | | | | | | | | | |
| 0 | | | 1.60 | 1.410 | 0.441 | 44 | 40 | 85 | 11 | 13 | 0.28 | 0.39 | 2.5 | 4.6 |
| 2.5 | | | 1.56 | 1.459 | 0.470 | 50 | 40 | 93 | 11 | 17 | 0.29 | 0.37 | 2.8 | 6.7 |
| 10 | | | 1.56 | 1.638 | 0.475 | 42 | 40 | 83 | 11 | 16 | 0.30 | 0.36 | 2.7 | 6.9 |
| 20 | | | 1.63 | 1.385 | 0.414 | 42 | 36 | 100 | 11 | 17 | 0.27 | 0.54 | 2.9 | 6.8 |
| LSD 10 % | | | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.07 | NS | NS |

*Note: LSD = least significant difference; NS = no significant difference*

Table **39. Suggested Critical Plant Nutrient Levels**

| | *N* | *P* | *K* | *Ca* | *Mg* | *S* | *Mn* | *Zn* | *Fe* | *Cu* | *B* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *%* | | | | | | *mg/kg* | | |
| Corn* | 2.9 | 0.25 | 1.90 | 0.40 | 0.15 | 0.15 | 15 | 15 | 25 | 5 | 10 |
| Soybeans† | | 0.25 | 2.00 | 0.40 | 0.25 | 0.15 | 20 | 15 | 30 | 5 | 25 |

* *Leaf opposite and below the ear at tasseling*
† *Fully developed leaf and petiole at early podding*

## SUMMARY

A two-year study was conducted to assess the risks and benefits of applying air-dried alum sludge from Peoria's water treatment plant to farmland used for growing corn and soybeans. Determinations were made of the effects of sludge application on soil nutrients and physical characteristics, corn and soybean yields and plant parameters, and the uptake and accumulation of heavy metals and other nutrients in plant tissues and grains.

Alum sludge was applied by hand at rates of 0, 2.5, 10, and 20 tons per acre (t/a) to 15-foot by 30-foot test plots prior to the planting in 1986. No alum sludge was applied to the plots in 1987. Each treatment (application rate) was replicated three times. In 1986, treatments were applied in a completely randomized design for soybeans and in a randomized block design for corn. In 1987, corn and soybeans were reversed between the two groups of plots.

The major plant nutrients and micronutrients in alum sludge from Peoria's water treatment plant were generally greater than those in the test plot soil and lower than those in sewage sludge from Peoria. The effects of alum sludge application on soil properties were evaluated. Soil properties examined were TS, organic matter, percent moisture, bulk density, pH, acidity, CEC, major forms of nitrogen, Bray P-1, total phosphorus, K, A1, B, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Ni, Zn, and particle size distribution.

The soil test data showed that soils in both corn and soybean plots were generally not significantly affected by the alum sludge applications. Occasional differences occurred among sludge-treated and untreated soils. However, they were never consistent for a series of eight collections for each treatment.

For the 1986 study, corn yields in the plots treated with alum sludge at the rates of 2.5 and 10 t/a were significantly lower than those in the plots treated with 0 and 20 t/a. Corn yields appeared to be related to plant populations. However, the corn yields and the plant populations in the highest-rate (20 t/a) plots were not affected by the alum sludge addition.

In 1987, corn yields in the 2.5 t/a plots were significantly less than in the 10 t/a plots; overall, corn yields in the sludge-treated plots were not statistically different from those in the non-treated plots. The corn yields and plant populations were apparently not affected by the sludge applications made in 1986. For both years, other corn parameters, soybean yields, and soybean plant parameters were not impacted by alum sludge applications.

Alum sludge does not contain enough nutrient value to provide a fertilizer effect. Nutrients and heavy metals (N, P, K, Ca, Mg, Mn, Zn, Fe, Cu, Al, Cd, Cr, Pb, Ni, crude protein, and moisture content) in grains, whole plants, and leaves were generally not significantly changed by the sludge applications. None of the nutrient levels were increased significantly by the nutrients in the sludge. The heavy metals levels were higher in the whole plants **and** leaves and lower in the grains.

# CONCLUSIONS

In this study the application of air-dried alum sludge on corn and soybean fields did not have any beneficial or adverse effects on corn or soybeans and did not alter the soil characteristics. It appears that there are no detrimental effects from the application of water treatment plant alum sludge at rates of up to 20 t/a to agricultural tracts in Illinois used for raising corn and soybeans.

The variability in corn yields might have been caused by poor seedbed preparation and dry soil conditions. Alum sludge has no fertilizer value and does not increase heavy metal accumulation in crops or heavy metal uptake in plant tissues.

On the basis of the two-year study, the following suggestions and recommendations are offered: Land application of alum sludge appears to be a viable method with no apparent environmental degradation. Applying raw liquid alum sludge seems impractical for most water treatment plants. Dewatering of alum sludge (through methods such as lagooning) is needed to reduce the cost of transportation. However, lagoons require land. Pulverization of sludge before application would be desirable.

The only no-cost disposal method is to discharge alum sludge directly into receiving waters. In Illinois, direct discharge requires a permit. Currently, treatment of alum sludge is required prior to final disposal.

The results of this study indicate that air-dried alum sludge can be applied to farmland without detrimental effects. Therefore suitable land disposal may be a feasible alternative. Alum sludge contains few nutrients and most likely will not cause contamination of surface and ground waters.

# RECOMMENDATIONS

• Long-term laboratory and greenhouse studies on alum sludge application on soil are needed before additional field studies are carried out.

• Greenhouse studies are needed to determine the best method and time of alum sludge application, to study the use of more than one water treatment plant as a source of alum sludge, and to study the land application of alum sludge for growing vegetables, wheat, rye, oats, and other crops.

• Additional information is needed on the maximum alum sludge application rate feasible for many plants and root crops. In this study, the highest rate (20 t/a) generally showed no effect on corn and soybeans.

• Air-dried alum sludge needs to be ground to powder form to eliminate clumps when the sludge is applied to the soil. It can also be applied in a suspended liquid form.

• The benefits and risks of the use of combined alum sludge and wastewater sludge should be evaluated.

• The possibility of using an irrigation system to apply alum sludge should be investigated.

• The rate at which the heavy metals move through the ground should be determined.

• Scientific data are needed on land application of lime sludge, which has been practiced on Illinois farms for many years.

# REFERENCES


Black, C.A. (ed.) 1973. *Methods of Soil Analysis.* 1st ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, 1,572 p.

Bugbee, G.J., and C.R. Frink. 1985. *Alum Sludge as a Soil Amendment: Effects on Soil Properties and Plant Growth.* Bulletin 829, Connecticut Agricultural Experiment Station, New Haven, 7 p. (Nov.).

Elliott, HA, B.A. Dempsey, and J. DeWolfe. 1989. Soil *Metal Loading and Phosphorus Fertility Effects from Land Application of Water Treatment Sludges.* Proceedings, AWWA/WPCF Joint Residuals Management Conference, San Diego, CA, Aug. 13-16, p. 5C/3.

Garcia, W.J., et al. 1979. *Translocation and Accumulation of Seven Heavy Metals in Tissues of Corn Plants Grown on Sludge-Treated Strip-Mined Soil.* Journal of Agricultural and Food Chemistry, 27(5):1088-1094.

Garcia, W.J., et al. 1981. *Metal Accumulation and Crop Yield for a Variety of Edible Crops Grown in Diverse Soil Media Amended with Sewage Sludge.* Environmental Science and Technology, 15(7):793-804.

Grabarek, R.J., and E.C. Krug. 1987. *Silvicultural Application of Alum Sludge.* Journal of the American Water Works Association, 79(6):89-98.

Guy, H.P. 1969. *Laboratory Theory and Methods for Sediment Analysis* (Book 5, Chapter C1). In *Techniques of Water-Resources Investigations of the United States Geological Survey,* U.S. Government Printing Office, Washington, DC.

Horwitz, W. (ed.) 1980. *Methods of Analysis of the Association of Official Analytical Chemists.* 13th ed. Association of Official Analytical Chemists Corp., Arlington, VA.

Illinois Environmental Protection Agency (IEPA). 1982. *Illinois EPA Sludge Regulation Guidance Document.* IEPA/ENV/82-014, Springfield, IL, 28 p.

Illinois Environmental Protection Agency (IEPA). 1984. *Design Criteria for Sludge Application on Land.* Title 35, Subtitle C, Chapter II, Part 391, IEPA, Springfield, IL, 32 p.

Jackson, M.L. 1958. *Soil Chemical Analysis.* Prentice-Hall, Englewood Cliffs, NJ, 498 p.

Kelling, K.A., et al. 1977. *A Field Study of Agricultural Use of Sewage Sludge: III. Effect on Uptake and Extractability of Sludge-Borne Metals.* Journal of Environmental Quality, 6(4):352-358.

Little, T.M., and F.J. Hills. 1978. *Agricultural Experimentation.* John Wiley & Sons, New York, 35 p.

Naylor, L.M., et al. 1987. *Uptake of Cadmium and Zinc by Corn on Sludge-Treatment Soils.* Biocycle, 28(4):37-41.

Page, AX. (ed.) 1982. *Methods of Soil Analysis.* 2d ed. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Russell, G.A. 1980. *Agricultural Application of Lime Softening Residue.* Presented at the Illinois AWWA Section Meeting (March).

*Standard Methods for the Examination of Water and Wastewater.* 1985. 16th ed. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, New York, NY.

University of Illinois. 1987. *Illinois Agronomy Handbook, 1987-1988.* College of Agriculture, Cooperative Extension Service, Circular 1266, p. 38.

Wang, W.C. 1975. *Determination of Cation-Exchange Capacity of Suspended Sediment.* Water Resources Bulletin, 11(5):1052-1057.

Appendix A-1. Daily Precipitation Records at Monmouth, Illinois - 1986

| Date | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | tr | | .01 | .52 | | .01 | | | .31 | | |
| 2 | | | | | | | .70 | | | .04 | .17 | .54 |
| 3 | .09 | tr | | .17 | | | | | | 2.18 | .01 | .13 |
| 4 | | .60 | .02 | .01 | | .03 | | | .15 | .25 | | |
| 5 | tr | .23 | | .05 | | .34 | | tr | | .01 | tr | |
| 6 | | .05 | .13 | | .10 | .20 | | .66 | | | | |
| 7 | | .32 | tr | | .27 | .25 | .02 | .04 | .12 | | | .57 |
| 8 | | | | | .02 | | .06 | .87 | | | .01 | .29 |
| 9 | | | | | | | 1.52 | | | tr | | .11 |
| 10 | | | .08 | | | .10 | .19 | | | .01 | | tr |
| 11 | | | .23 | | .02 | | .10 | | .70 | | .05 | |
| 12 | | tr | .02 | | | .04 | 1.41 | | .23 | .94 | tr | |
| 13 | | | .08 | .08 | tr | | .01 | tr | tr | tr | tr | |
| 14 | | .06 | tr | .38 | .09 | | .30 | .31 | .01 | .17 | | |
| 15 | | | tr | tr | .05 | .35 | | .01 | | | | |
| 16 | | | | tr | .11 | tr | | .01 | | | | |
| 17 | | .42 | | | 1.62 | | | | .02 | | | tr |
| 18 | | tr | .12 | | 1.04 | | | .38 | .28 | | tr | |
| 19 | | | .25 | tr | | | | | .65 | | tr | |
| 20 | | tr | | | | | | | .73 | | .41 | |
| 21 | | tr | | tr | | | | | .03 | | tr | |
| 22 | | | | | | .05 | | | | | | |
| 23 | | .04 | | | | .21 | | | 1.22 | .01 | .10 | |
| 24 | | .30 | | | | .02 | | | .65 | tr | | |
| 25 | tr | | | | | | .27 | | 1.84 | .49 | | |
| 26 | | tr | .07 | .04 | .55 | | | 1.05 | | 1.10 | .03 | |
| 27 | | .19 | | | .27 | | | | | .10 | | |
| 28 | tr | tr | | .13 | tr | .16 | | | .08 | | | |
| 29 | tr | | | tr | .01 | .01 | .27 | | .24 | | | |
| 30 | | | .03 | .19 | .02 | 1.13 | | | 2.16 | | tr | .01 |
| 31 | tr | | | | | | 1.49 | | | | | |
| Total | .09 | 2.21 | 1.03 | 1.06 | 4.69 | 2.89 | 6.35 | 3.33 | 9.11 | 5.61 | .78 | 1.65 |
| Cum. total | .09 | 2.30 | 3.33 | 4.39 | 9.08 | 11.97 | 18.32 | 21.65 | 30.76 | 36.37 | 37.15 | 38.80 |

## Appendix A-2. Daily Precipitation Records at Monmouth, Illinois - 1987

| **Date** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **June** | **July** | **Aug** | **Sept** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | tr | | .66 | | | .40 | .06 | .57 | | | .94 | .01 |
| 2 | .09 | | tr | .01 | | .05 | | | | | .18 | tr |
| 3 | | | | | .05 | tr | | | | | .01 | |
| 4 | | | | | tr | | | .90 | | | | |
| 5 | | | | | | | .05 | | | | | |
| 6 | | .04 | | | | | | | | tr | | |
| 7 | | | | | | | | | .36 | tr | | .31 |
| 8 | | | | | | | tr | .15 | .08 | | tr | .09 |
| 9 | | | | | | | | .22 | | | .10 | .06 |
| 10 | .30 | | | | | | | | | tr | | |
| 11 | | | | tr | | | | | .04 | .01 | | .04 |
| 12 | | | tr | tr | | .20 | .01 | | .06 | | | |
| 13 | | | | .29 | | | .03 | .46 | | | | |
| 14 | | | | .75 | | | .02 | 1.01 | | | | |
| 15 | | | .16 | .03 | | | .67 | 1.11 | .23 | tr | | .99 |
| 16 | | | .22 | tr | | | | | .23 | | .18 | .03 |
| 17 | | | | | | | | 1.01 | 1.09 | .07 | .56 | |
| 18 | .08 | | .12 | | tr | | | | .03 | | .01 | |
| 19 | .15 | | .36 | | | | | | tr | .01 | tr | .12 |
| 20 | | | | | .23 | .79 | | | | .21 | | |
| 21 | | | | | .05 | .39 | | .09 | .12 | tr | | |
| 22 | **tr** | | | .18 | | | | | | | | |
| 23 | | | .01 | .21 | | | | tr | | | .08 | |
| 24 | | | tr | tr | | | | | | .22 | | |
| 25 | | | .06 | | .03 | .20 | tr | .41 | | | .36 | .05 |
| 26 | | | tr | | .22 | **.06** | | 1.27 | | | tr | |
| 27 | .03 | .02 | tr | .03 | | | | .04 | | tr | tr | |
| 28 | | tr | | | tr | | | .02 | | tr | .55 | .80 |
| 29 | tr | | .87 | | | tr | | | 1.33 | | .36 | .05 |
| 30 | tr | | tr | | tr | .01 | .03 | | | | .07 | |
| 31 | tr | | | | .78 | | | | | | | |
| Total | .65 | .06 | 3.00 | 1.50 | 1.36 | 2.10 | .87 | 7.26 | 3.57 | .52 | 3.40 | 3.78 |
| Cum. total | .65 | .71 | 3.71 | 5.21 | 6.57 | 8.67 | 9.54 | 16.80 | 20.37 | 20.89 | 24.29 | 28.07 |

Appendix B. Summary of Weather Data at Monmouth, Illinois

| Month | Air temperature Degrees, F. (max.) | (min.) | Relative humidity (%) (max.) | (%) (min.) | Average soil temperature Degrees. F. Sod (max.) | Sod (min.) | Bare soil (max.) | Bare soil (min.) | Precipitation (Inches) Month | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | | | | | | |
| Jan. | 34 | 16 | 91 | 57 | 28 | 26 | 29 | 24 | 0.09 | 0.09 |
| Feb. | 31 | 15 | 94 | 68 | 30 | 29 | 31 | 30 | 2.21 | 2.30 |
| Mar. | 50 | 31 | 93 | 52 | 36 | 33 | 41 | 35 | 1.03 | 3.33 |
| Apr. | 67 | 41 | 93 | 39 | 54 | 48 | 63 | 49 | 1.06 | 4.39 |
| May | 73 | 52 | 95 | 50 | 65 | 58 | 72 | 59 | 4.69 | 9.08 |
| June | 82 | 61 | 99 | 53 | 77 | 68 | 86 | 90 | 2.89 | 11.97 |
| July | 85 | 69 | 100 | 61 | 82 | 74 | 90 | 75 | 6.35 | 18.32 |
| Aug. | 79 | 57 | 100 | 52 | 75 | 68 | 81 | 66 | 3.33 | 21.65 |
| Sep. | 78 | 58 | 100 | 55 | 70 | 65 | 74 | 63 | 9.11 | 30.76 |
| Oct. | 63 | 44 | 100 | 60 | 59 | *55* | 61 | 51 | 5.61 | 36.37 |
| Nov. | 43 | 26 | 98 | 59 | 42 | 39 | 41 | 36 | 0.78 | 37.15 |
| Dec. | 37 | 24 | 97 | 64 | 34 | 33 | 32 | 31 | 1.65 | 38.80 |
| **1987** | | | | | | | | | | |
| Jan. | 31 | 17 | 96 | 65 | 33 | 32 | 31 | 31 | 0.65 | 0.65 |
| Feb. | 44 | 26 | 97 | 50 | 34 | 32 | 35 | 32 | 0.06 | 0.71 |
| Mar. | 52 | 32 | 93 | 48 | 43 | 39 | 46 | 38 | 3.00 | 3.71 |
| Apr. | 65 | 40 | 88 | 38 | 53 | 47 | 60 | 47 | 1.50 | 5.21 |
| May | 80 | 54 | 89 | 38 | 68 | 60 | 79 | 63 | 1.36 | 6.57 |
| June | 85 | 62 | 99 | 47 | 80 | 70 | 87 | 71 | 2.10 | 8.67 |
| July | 89 | 66 | 100 | 51 | 85 | 75 | 93 | 77 | 0.87 | 9.54 |
| Aug. | 84 | 63 | 100 | 55 | 80 | 72 | 84 | 71 | 7.26 | 16.80 |
| Sep. | 77 | 53 | 100 | 48 | 69 | 63 | 75 | 61 | 3.57 | 20.37 |
| Oct. | 59 | 34 | 97 | 49 | 53 | 47 | 57 | 44 | 0.52 | 20.89 |
| Nov. | 52 | 35 | 98 | 69 | 46 | 42 | 47 | 40 | 3.40 | 24.29 |
| Dec. | 36 | 24 | 94 | 70 | 35 | 34 | 35 | 33 | 3.78 | 28.07 |

## Appendix C1. Percent Total Solids in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 80.5 | 83.5 | 79.0 | 5/21 | 0 | 78.2 | 80.9 | 79.1 |
| | 2.5 | 81.1 | 79.7 | 80.7 | | 2.5 | 78.5 | 79.0 | 82.2 |
| | 10 | 79.9 | 81.3 | 80.6 | | 10 | 80.0 | 79.6 | 80.7 |
| | 20 | 78.0 | 80.6 | 80.4 | | 20 | 79.8 | 80.4 | 80.0 |
| 6/13 | 0 | 80.5 | 80.4 | 78.8 | 7/18 | 0 | 79.1 | 82.6 | 82.9 |
| | 2.5 | 79.5 | 79.8 | 80.4 | | 2.5 | 79.6 | 81.2 | 82.1 |
| | 10 | 79.7 | 81.4 | 80.2 | | 10 | 81.6 | 82.1 | 81.7 |
| | 20 | 78.3 | 81.0 | 78.6 | | 20 | 81.8 | 82.8 | 81.9 |
| 8/13 | 0 | 78.0 | 78.8 | 76.9 | 8/29 | 0 | 79.2 | 81.3 | 79.4 |
| | 2.5 | 78.3 | 77.9 | 77.6 | | 2.5 | 79.4 | 79.4 | 80.8 |
| | 10 | 78.7 | 78.3 | 76.8 | | 10 | 81.3 | 80.4 | 83.4 |
| | 20 | 75.6 | 78.4 | 76.9 | | 20 | 80.7 | 81.5 | 81.5 |
| 10/21 | 0 | 76.8 | 77.9 | 76.4 | 10/21 | 0 | 78.0 | 81.4 | 79.0 |
| | 2.5 | 76.6 | 77.0 | 77.1 | | 2.5 | 78.2 | 79.2 | 79.9 |
| | 10 | 76.8 | 76.8 | 77.4 | | 10 | 80.6 | 80.2 | 81.2 |
| | 20 | 74.4 | 77.0 | 76.7 | | 20 | 80.3 | 81.3 | 80.8 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 78.2 | 81.9 | 79.1 | 4/28 | 0 | 78.7 | 79.6 | 78.3 |
| | 2.5 | 78.1 | 79.8 | 80.8 | | 2.5 | 78.8 | 78.2 | 79.2 |
| | 10 | 80.0 | 80.1 | 81.9 | | 10 | 78.4 | 78.7 | 78.7 |
| | 20 | 80.1 | 81.1 | 81.4 | | 20 | 77.0 | 79.2 | 78.3 |
| 6/26 | 0 | 82.7 | 82.7 | 82.2 | 7/17 | 0 | 84.0 | 85.4 | 82.0 |
| | 2.5 | 83.8 | 82.4 | 83.1 | | 2.5 | 84.4 | 83.1 | 83.0 |
| | 10 | 82.5 | 81.8 | 84.7 | | 10 | 82.8 | 83.9 | 83.1 |
| | 20 | 82.4 | 83.0 | 85.1 | | 20 | 82.2 | 83.5 | 81.9 |
| 8/21 | 0 | 78.2 | 81.7 | 79.9 | 9/04 | 0 | 80.3 | 81.6 | 79.1 |
| | 2.5 | 79.2 | 79.6 | 82.4 | | 2.5 | 80.9 | 81.4 | 81.2 |
| | 10 | 81.0 | 80.2 | 83.4 | | 10 | 80.8 | 82.1 | 81.3 |
| | 20 | 80.6 | 81.3 | 82.4 | | 20 | 77.5 | 80.1 | 80.3 |
| 10/15 | 0 | 79.3 | 83.4 | 81.1 | 10/15 | 0 | 81.3 | 81.3 | 79.5 |
| | 2.5 | 79.5 | 81.6 | 83.8 | | 2.5 | 80.7 | 81.0 | 80.6 |
| | 10 | 82.8 | 81.4 | 84.4 | | 10 | 80.5 | 81.8 | 81.1 |
| | 20 | 82.1 | 83.0 | 83.2 | | 20 | 79.7 | 80.7 | 79.4 |

Note: The crops were rotated between the two groups of test plots for the second year.

Appendix C2. Percent Organic Matter in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| **4/24** | 0 | 6.9 | 5.6 | 6.7 | 5/21 | 0 | 6.5 | 5.9 | 5.0 |
| | 2.5 | 7.0 | 6.7 | 6.6 | | 2.5 | 5.9 | 5.8 | 4.2 |
| | 10 | 6.6 | 6.6 | 6.5 | | 10 | 4.1 | 3.8 | 3.2 |
| | 20 | 7.8 | 6.4 | 6.4 | | 20 | 4.1 | 3.5 | 4.3 |
| 6/13 | 0 | 6.4 | 5.6 | 6.6 | 7/18 | 0 | 7.1 | 3.4 | 5.2 |
| | 2.5 | 6.1 | 6.8 | 7.0 | | 2.5 | 7.1 | 6.2 | 5.5 |
| | 10 | 6.5 | 6.3 | 6.6 | | 10 | 3.8 | 4.9 | 4.0 |
| | 20 | 10.8 | 6.7 | 6.6 | | 20 | 4.0 | 3.7 | 3.4 |
| 8/13 | 0 | 6.6 | 5.4 | 6.8 | 8/29 | 0 | 6.8 | 3.6 | 5.3 |
| | 2.5 | 6.7 | 6.5 | 7.5 | | 2.5 | 6.7 | 5.8 | 4.8 |
| | 10 | 6.5 | 6.9 | 7.1 | | 10 | 4.3 | 4.7 | 3.6 |
| | 20 | 7.9 | 6.5 | 6.8 | | 20 | 4.4 | 3.9 | 4.2 |
| 10/2 | 10 | 7.1 | 5.8 | 7.1 | 10/21 | 0 | 6.8 | 3.7 | 5.7 |
| | 2.5 | 6.8 | 6.7 | 6.9 | | 2.5 | 6.6 | 5.9 | 5.0 |
| | 10 | 6.9 | 6.5 | 6.5 | | 10 | 4.2 | 4.9 | 3.8 |
| | 20 | 8.4 | 6.4 | 6.6 | | 20 | 4.4 | 4.2 | 4.5 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 5.9 | 3.3 | 5.2 | 4/28 | 0 | 7.0 | 5.6 | 6.6 |
| | 2.5 | 6.0 | 5.5 | 4.5 | | 2.5 | 7.0 | 6.5 | 7.1 |
| | 10 | 3.5 | 4.5 | 3.5 | | 10 | 7.0 | 6.5 | 6.4 |
| | 20 | 4.0 | 4.0 | 4.1 | | 20 | 8.0 | 6.6 | 6.3 |
| 6/26 | 0 | 6.3 | 3.5 | 5.5 | 7/17 | 0 | 7.2 | 6.1 | 7.3 |
| | 2.5 | 6.3 | 5.4 | 5.8 | | 2.5 | 7.1 | 6.9 | 7.3 |
| | 10 | 4.1 | 4.6 | 4.2 | | 10 | 7.3 | 6.7 | 6.8 |
| | 20 | 4.1 | 4.0 | 4.4 | | 20 | 8.4 | 6.9 | 6.3 |
| 8/21 | 0 | 6.5 | 3.4 | 5.4 | 9/04 | 0 | 6.8 | 5.6 | 7.0 |
| | 2.5 | 6.2 | 5.6 | 4.9 | | 2.5 | 6.8 | 6.5 | 6.8 |
| | 10 | 3.9 | 7.6 | 3.5 | | 10 | 7.1 | 6.6 | 6.5 |
| | 20 | 3.8 | 3.8 | 4.0 | | 20 | 8.3 | 7.0 | 6.7 |
| 10/15 | 0 | 6.8 | 3.7 | 5.4 | 10/15 | 0 | 6.8 | 5.7 | 6.6 |
| | 2.5 | 6.7 | 5.8 | 5.1 | | 2.5 | 7.3 | 6.5 | 6.7 |
| | 10 | 4.3 | 4.7 | 3.5 | | 10 | 6.7 | 6.4 | 6.2 |
| | 20 | 4.3 | 4.1 | 4.4 | | 20 | 8.0 | 6.4 | 6.3 |

## Appendix C3. Percent Moisture in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 19.5 | 16.5 | 21.0 | 5/21 | 0 | 21.8 | 19.1 | 20.9 |
| | 2.5 | 18.9 | 20.3 | 19.3 | | 2.5 | 21.5 | 21.0 | 17.8 |
| | 10 | 20.1 | 18.7 | 19.4 | | 10 | 20.0 | 20.4 | 19.3 |
| | 20 | 22.0 | 19.4 | 19.6 | | 20 | 20.2 | 19.6 | 20.0 |
| 6/13 | 0 | 19.5 | 19.6 | 21.2 | 7/18 | 0 | 20.9 | 17.4 | 17.1 |
| | 2.5 | 20.5 | 20.2 | 19.6 | | 2.5 | 20.4 | 18.8 | 17.9 |
| | 10 | 20.3 | 18.6 | 19.8 | | 10 | 18.4 | 17.9 | 18.3 |
| | 20 | 21.7 | 19.0 | 21.4 | | 20 | 18.2 | 17.2 | 18.1 |
| 8/13 | 0 | 22.0 | 21.2 | 23.1 | 8/29 | 0 | 20.8 | 18.7 | 20.6 |
| | 2.5 | 21.7 | 22.1 | 22.4 | | 2.5 | 20.6 | 20.6 | 19.2 |
| | 10 | 21.3 | 21.7 | 23.2 | | 10 | 18.7 | 19.6 | 16.6 |
| | 20 | 24.4 | 21.6 | 23.1 | | 20 | 19.3 | 18.5 | 18.5 |
| 10/21 | 0 | 23.2 | 22.1 | 23.6 | 10/2 | 10 | 22.0 | 18.6 | 21.0 |
| | 2.5 | 23.4 | 23.0 | 22.9 | | 2.5 | 21.8 | 20.8 | 20.1 |
| | 10 | 23.2 | 23.2 | 22.6 | | 10 | 19.4 | 19.8 | 18.8 |
| | 20 | 25.6 | 23.0 | 23.3 | | 20 | 19.7 | 18.7 | 19.2 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 21.8 | 18.1 | 20.9 | 4/28 | 0 | 21.3 | 20.4 | 21.7 |
| | 2.5 | 21.9 | 20.2 | 19.2 | | 2.5 | 21.2 | 21.8 | 20.8 |
| | 10 | 20.0 | 19.9 | 18.1 | | 10 | 21.6 | 21.3 | 21.3 |
| | 20 | 19.9 | 18.9 | 18.6 | | 20 | 23.0 | 20.8 | 21.7 |
| 6/26 | 0 | 17.3 | 17.3 | 17.8 | 7/17 | 0 | 16.0 | 14.6 | 18.0 |
| | 2.5 | 16.2 | 17.6 | 16.9 | | 2.5 | 15.6 | 16.9 | 17.0 |
| | 10 | 17.5 | 18.2 | 15.3 | | 10 | 17.2 | 16.1 | 16.9 |
| | 20 | 17.5 | 17.0 | 14.9 | | 20 | 17.8 | 16.5 | 18.1 |
| 8/21 | 0 | 21.8 | 18.3 | 20.1 | 9/04 | 0 | 19.7 | 18.4 | 20.9 |
| | 2.5 | 20.8 | 20.4 | 17.6 | | 2.5 | 19.1 | 18.6 | 18.8 |
| | 10 | 19.0 | 19.8 | 16.6 | | 10 | 19.2 | 17.9 | 18.7 |
| | 20 | 19.4 | 18.7 | 17.6 | | 20 | 22.5 | 19.9 | 19.7 |
| 10/15 | 0 | 20.7 | 16.6 | 18.9 | 10/15 | 0 | 18.7 | 18.7 | 20.5 |
| | 2.5 | 20.5 | 18.4 | 16.2 | | 2.5 | 19.3 | 19.0 | 19.4 |
| | 10 | 17.2 | 18.6 | 15.6 | | 10 | 19.5 | 18.2 | 18.9 |
| | 20 | 17.9 | 17.0 | 16.8 | | 20 | 20.3 | 19.3 | 20.6 |

Appendix C4. Specific Gravity (g/cm$^3$) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 2.08 | 2.07 | 2.04 | 5/21 | 0 | 1.46 | 2.10 | 1.87 |
| | 2.5 | 2.01 | 1.99 | 2.09 | | 2.5 | 1.76 | 2.03 | 1.88 |
| | 10 | 2.10 | 2.03 | 2.04 | | 10 | 2.17 | 1.78 | 1.81 |
| | 20 | 2.00 | 2.12 | 2.04 | | 20 | 2.14 | 2.03 | 1.68 |
| 6/13 | 0 | 1.56 | 1.35 | 1.66 | 7/18 | 0 | 1.37 | 1.69 | 1.43 |
| | 2.5 | 1.59 | 1.68 | 1.65 | | 2.5 | 1.55 | 1.28 | 1.31 |
| | 10 | 1.42 | 1.64 | 1.96 | | 10 | 1.67 | 1.76 | 1.81 |
| | 20 | 1.63 | 1.72 | 1.72 | | 20 | 1.90 | 1.46 | 1.70 |
| 8/13 | 0 | 1.34 | 1.32 | 1.37 | 8/29 | 0 | 1.51 | 1.42 | 1.36 |
| | 2.5 | 1.21 | 1.04 | 1.45 | | 2.5 | 1.47 | 1.52 | 1.26 |
| | 10 | 1.30 | 1.22 | 1.38 | | 10 | 1.49 | 1.48 | 1.49 |
| | 20 | 1.28 | 1.09 | 1.42 | | 20 | 1.45 | 1.42 | 1.44 |
| 10/21 | 0 | 1.12 | 1.24 | 1.30 | 10/21 | 0 | 1.32 | 1.50 | 1.28 |
| | 2.5 | 1.14 | 1.34 | 1.28 | | 2.5 | 1.54 | 1.31 | 1.39 |
| | 10 | 1.24 | 1.39 | 1.33 | | 10 | 1.56 | 1.42 | 1.47 |
| | 20 | 1.15 | 1.19 | 1.15 | | 20 | 1.44 | 1.47 | 1.41 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 1.36 | 1.59 | 1.26 | 4/28 | 0 | 1.44 | 1.64 | 1.37 |
| | 2.5 | 1.38 | 1.38 | 1.47 | | 2.5 | 1.40 | 1.42 | 1.43 |
| | 10 | 1.45 | 1.54 | 1.53 | | 10 | 1.34 | 1.46 | 1.43 |
| | 20 | 1.66 | 1.43 | 1.40 | | 20 | 1.25 | 1.28 | 1.40 |
| 6/26 | 0 | 1.44 | 1.69 | 1.43 | 7/17 | 0 | 1.42 | 1.29 | 1.21 |
| | 2.5 | 1.17 | 1.46 | 1.04 | | 2.5 | 1.20 | 1.14 | 1.27 |
| | 10 | 1.70 | 1.27 | 1.45 | | 10 | 1.39 | 1.20 | 1.30 |
| | 20 | 1.58 | 1.58 | 1.34 | | 20 | 1.43 | 1.39 | 1.34 |
| 8/21 | 0 | 1.28 | 1.55 | 1.46 | 9/04 | 0 | 1.20 | 1.29 | 1.26 |
| | 2.5 | 1.25 | 1.32 | 1.06 | | 2.5 | 1.21 | 1.45 | 1.35 |
| | 10 | 1.53 | 1.38 | 1.49 | | 10 | 1.41 | 1.24 | 1.35 |
| | 20 | 1.64 | 1.51 | 1.53 | | 20 | 1.26 | 1.23 | 1.37 |
| 10/15 | 0 | 1.40 | 1.73 | 1.32 | 10/15 | 0 | 1.13 | 1.36 | 1.29 |
| | 2.5 | 1.43 | 1.17 | 1.41 | | 2.5 | 1.12 | 1.39 | 1.41 |
| | 10 | 1.55 | 1.45 | 1.19 | | 10 | 1.42 | 1.24 | 1.35 |
| | 20 | 1.55 | 1.55 | 1.23 | | 20 | 1.25 | 1.15 | 1.36 |

Appendix C5. pH in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 5.05 | 5.07 | 7.23 | 5/21 | 0 | 5.30 | 5.92 | 4.86 |
| | 2.5 | 5.31 | 5.13 | 5.91 | | 2.5 | 5.64 | 5.43 | 7.20 |
| | 10 | 5.37 | 5.36 | 5.72 | | 10 | 5.82 | 5.47 | 7.50 |
| | 20 | 5.26 | 5.52 | 6.56 | | 20 | 5.87 | 6.10 | 7.05 |
| 6/13 | 0 | 5.21 | 4.93 | 7.12 | 7/18 | 0 | 5.35 | 5.88 | 5.32 |
| | 2.5 | 5.26 | 4.98 | 5.75 | | 2.5 | 5.67 | 5.40 | 6.74 |
| | 10 | 5.03 | 4.92 | 6.09 | | 10 | 5.81 | 5.72 | 7.54 |
| | 20 | 5.62 | 5.23 | 6.15 | | 20 | 5.89 | 5.99 | 7.16 |
| 8/13 | 0 | 5.17 | 4.92 | 6.42 | 8/29 | 0 | 5.26 | 5.96 | 5.26 |
| | 2.5 | 5.03 | 5.11 | 5.72 | | 2.5 | 5.75 | 5.53 | 7.50 |
| | 10 | 5.63 | 5.18 | 5.93 | | 10 | 6.25 | 5.76 | 7.75 |
| | 20 | 5.54 | 5.35 | 6.39 | | 20 | 6.63 | 6.50 | 7.48 |
| 10/21 | 0 | 5.20 | 5.01 | 6.75 | 10/21 | 0 | 5.52 | 5.94 | 5.28 |
| | 2.5 | 5.22 | 5.13 | 5.78 | | 2.5 | 5.85 | 5.62 | 7.36 |
| | 10 | 5.37 | 5.30 | 6.14 | | 10 | 6.15 | 5.77 | 7.60 |
| | 20 | 5.73 | 5.67 | 6.74 | | 20 | 6.12 | 6.36 | 7.39 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 5.63 | 6.16 | 5.30 | 4/28 | 0 | 5.05 | 5.02 | 6.52 |
| | 2.5 | 5.51 | 5.61 | 7.25 | | 2.5 | 5.12 | 5.17 | 5.81 |
| | 10 | 6.51 | 5.83 | 7.45 | | 10 | 5.22 | 5.41 | 6.02 |
| | 20 | 6.18 | 7.40 | 6.75 | | 20 | 5.68 | 6.00 | 6.41 |
| 6/26 | 0 | 5.03 | 5.74 | 4.96 | 7/17 | 0 | 5.09 | 4.97 | 6.87 |
| | 2.5 | 5.02 | 5.17 | 6.55 | | 2.5 | 5.06 | 5.06 | 5.73 |
| | 10 | 5.77 | 5.27 | 7.30 | | 10 | 5.40 | 5.06 | 6.13 |
| | 20 | 5.95 | 6.15 | 6.60 | | 20 | 5.53 | 5.82 | 6.59 |
| 8/21 | 0 | 5.31 | 6.17 | 5.08 | 9/04 | 0 | 5.20 | 5.03 | 7.23 |
| | 2.5 | 5.68 | 6.42 | 7.40 | | 2.5 | 5.15 | 5.38 | 5.84 |
| | 10 | 6.03 | 6.18 | 7.63 | | 10 | 5.55 | 5.33 | 6.32 |
| | 20 | 6.52 | 6.91 | 7.54 | | 20 | 5.15 | 6.03 | 6.55 |
| 10/15 | 0 | 5.30 | 6.18 | 5.15 | 10/15 | 0 | 5.00 | 4.91 | 7.08 |
| | 2.5 | 5.41 | 5.14 | 7.18 | | 2.5 | 4.95 | 4.99 | 6.02 |
| | 10 | 6.34 | 5.64 | 7.60 | | 10 | 5.33 | 5.12 | 6.70 |
| | 20 | 6.45 | 6.61 | 7.30 | | 20 | 5.15 | 5.58 | 6.55 |

Appendix C6. Acidity (meq/100 g) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 0.32 | 0.42 | 0.03 | 5/21 | 0 | 0.18 | 0.12 | 0.64 |
| | 2.5 | 0.34 | 0.35 | 0.13 | | 2.5 | 0.13 | 0.19 | 0.07 |
| | 10 | 0.25 | 0.33 | 0.18 | | 10 | 0.16 | 0.32 | 0.03 |
| | 20 | 0.20 | 0.26 | 0.12 | | 20 | 0.22 | 0.23 | 0.06 |
| 6/13 | 0 | 0.24 | 0.71 | 0.04 | 7/18 | 0 | 0.22 | 0.18 | 0.47 |
| | 2.5 | 0.28 | 0.42 | 0.13 | | 2.5 | 0.16 | 0.22 | 0.13 |
| | 10 | 0.23 | 0.46 | 0.09 | | 10 | 0.19 | 0.18 | 0.05 |
| | 20 | 0.35 | 0.40 | 0.16 | | 20 | 0.14 | 0.17 | 0.09 |
| 8/13 | 0 | 0.27 | 0.74 | 0.05 | 8/29 | 0 | 0.28 | 0.15 | 0.64 |
| | 2.5 | 0.36 | 0.35 | 0.10 | | 2.5 | 0.10 | 0.25 | 0.09 |
| | 10 | 0.31 | 0.41 | 0.11 | | 10 | 0.16 | 0.19 | 0.08 |
| | 20 | 0.12 | 0.28 | 0.15 | | 20 | 0.26 | 0.07 | 0.08 |
| 10/21 | 0 | 0.33 | 0.76 | 0.07 | 10/21 | 0 | 0.23 | 0.11 | 0.74 |
| | 2.5 | 0.40 | 0.48 | 0.10 | | 2.5 | 0.09 | 0.16 | 0.06 |
| | 10 | 0.24 | 0.35 | 0.05 | | 10 | 0.07 | 0.23 | 0.04 |
| | 20 | 0.16 | 0.25 | 0.08 | | 20 | 0.14 | 0.11 | 0.04 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 0.07 | 0.02 | 0.29 | 4/28 | 0 | 0.25 | 0.38 | 0.04 |
| | 2.5 | 0.02 | 0.06 | 0.04 | | 2.5 | 0.22 | 0.17 | 0.04 |
| | 10 | 0.02 | 0.03 | 0.02 | | 10 | 0.14 | 0.11 | 0.04 |
| | 20 | 0.02 | 0.02 | 0.04 | | 20 | 0.10 | 0.06 | 0.04 |
| 6/26 | 0 | 0.16 | 0.04 | 0.27 | 7/17 | 0 | 0.42 | 0.31 | 0.06 |
| | 2.5 | 0.13 | 0.10 | 0.01 | | 2.5 | 0.01 | 0.23 | 0.06 |
| | 10 | 0.04 | 0.14 | 0.05 | | 10 | 0.06 | 0.27 | 0.04 |
| | 20 | 0.01 | 0.05 | 0.01 | | 20 | 0.09 | 0.11 | 0.07 |
| 8/21 | 0 | 0.08 | 0.12 | 0.40 | 9/04 | 0 | 0.13 | 0.33 | 0.02 |
| | 2.5 | 0.01 | 0.22 | 0.07 | | 2.5 | 0.30 | 0.18 | 0.10 |
| | 10 | 0.09 | 0.05 | 0.05 | | 10 | 0.02 | 0.13 | 0.06 |
| | 20 | 0.01 | 0.06 | 0.05 | | 20 | 0.10 | 0.13 | 0.05 |
| 10/15 | 0 | 0.17 | 0.03 | 0.27 | 10/15 | 0 | 0.26 | 0.39 | 0.07 |
| | 2.5 | 0.13 | 0.16 | 0.04 | | 2.5 | 0.02 | 0.27 | 0.07 |
| | 10 | 0.05 | 0.10 | 0.04 | | 10 | 0.34 | 0.18 | 0.09 |
| | 20 | 0.08 | 0.07 | 0.04 | | 20 | 0.05 | 0.07 | 0.05 |

Appendix C7. Cation Exchange Capacity (meq/100 g) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 13.8 | 12.8 | 16.7 | 5/21 | 0 | 16.6 | 14.7 | 14.4 |
| | 2.5 | 14.3 | 13.2 | 15.7 | | 2.5 | 16.7 | 15.0 | 14.7 |
| | 10 | 14.9 | 11.9 | 13.1 | | 10 | 15.1 | 15.0 | 12.2 |
| | 20 | 14.1 | 11.3 | 14.4 | | 20 | 16.4 | 14.5 | 14.3 |
| 6/13 | 0 | 19.5 | 19.0 | 22.2 | 7/18 | 0 | 20.1 | 18.1 | 18.6 |
| | 2.5 | 18.4 | 20.0 | 21.8 | | 2.5 | 21.7 | 18.9 | 19.4 |
| | 10 | 19.9 | 19.2 | 20.2 | | 10 | 17.4 | 19.1 | 16.7 |
| | 20 | 23.9 | 18.8 | 22.2 | | 20 | 19.3 | 18.1 | 17.2 |
| 8/13 | 0 | 18.2 | 17.2 | 20.8 | 8/29 | 0 | 19.8 | 17.7 | 18.4 |
| | 2.5 | 18.9 | 20.6 | 21.6 | | 2.5 | 19.9 | 17.8 | 17.7 |
| | 10 | 14.7 | 17.0 | 18.2 | | 10 | 18.9 | 19.5 | 15.0 |
| | 20 | 20.8 | 17.8 | 20.6 | | 20 | 18.8 | 17.4 | 16.6 |
| 10/21 | 0 | 16.4 | 17.0 | 21.7 | 10/21 | 0 | 18.2 | 16.3 | 17.4 |
| | 2.5 | 16.9 | 15.8 | 20.3 | | 2.5 | 18.3 | 17.2 | 17.6 |
| | 10 | 16.7 | 15.7 | 18.8 | | 10 | 17.2 | 16.6 | 14.3 |
| | 20 | 20.7 | 16.8 | 19.7 | | 20 | 18.3 | 16.6 | 16.4 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 19.1 | 16.8 | 19.0 | 4/28 | 0 | 17.0 | 17.3 | 17.4 |
| | 2.5 | 19.2 | 18.7 | 17.1 | | 2.5 | 18.0 | 17.6 | 20.6 |
| | 10 | 18.1 | 18.2 | 14.6 | | 10 | 18.0 | 18.2 | 19.7 |
| | 20 | 19.4 | 16.3 | 16.9 | | 20 | 21.3 | 18.6 | 19.8 |
| 6/26 | 0 | 18.0 | 15.0 | 19.7 | 7/17 | 0 | 20.9 | 20.5 | 28.0 |
| | 2.5 | 21.6 | 17.4 | 15.7 | | 2.5 | 17.2 | 23.1 | 24.7 |
| | 10 | 22.6 | 20.7 | 16.2 | | 10 | 20.5 | 21.0 | 18.9 |
| | 20 | 16.9 | 24.5 | 20.4 | | 20 | 25.5 | 21.4 | 25.5 |
| 8/21 | 0 | 23.8 | 15.6 | 29.0 | 9/04 | 0 | 29.9 | 24.0 | 21.1 |
| | 2.5 | 22.5 | 16.4 | 22.0 | | 2.5 | 16.4 | 20.7 | 20.5 |
| | 10 | 17.9 | 25.7 | 24.3 | | 10 | 20.5 | 16.2 | 28.1 |
| | 20 | 23.3 | 24.9 | 23.3 | | 20 | 21.8 | 18.5 | 23.1 |
| 10/15 | 0 | 24.3 | 27.2 | 20.2 | 10/15 | 0 | 18.1 | 28.1 | 23.1 |
| | 2.5 | 26.8 | 27.5 | 27.3 | | 2.5 | 19.2 | 14.9 | 34.0 |
| | 10 | 30.1 | 27.2 | 13.1 | | 10 | 15.2 | 16.5 | 32.2 |
| | 20 | 38.7 | 24.8 | 25.9 | | 20 | 27.3 | 21.1 | 36.3 |

## Appendix C8. Ammonia Nitrogen (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 237 | 193 | 133 | 5/2 | 10 | 154 | 47 | 119 |
| | 2.5 | 259 | 185 | 340 | | 2.5 | 135 | 137 | 93 |
| | 10 | 171 | 244 | 406 | | 10 | 68 | 83 | 43 |
| | 20 | 190 | 273 | 141 | | 20 | 56 | 91 | 69 |
| 6/13 | 0 | 172 | 161 | 158 | 7/18 | 0 | 197 | 51 | 91 |
| | 2.5 | 153 | 168 | 159 | | 2.5 | 198 | 176 | 129 |
| | 10 | 170 | 182 | 162 | | 10 | 75 | 119 | 80 |
| | 20 | 217 | 171 | 160 | | 20 | 69 | 64 | 72 |
| 8/13 | 0 | 188 | 149 | 180 | 8/29 | 0 | 138 | 70 | 108 |
| | 2.5 | 205 | 186 | 178 | | 2.5 | 149 | 123 | 95 |
| | 10 | 204 | 181 | 184 | | 10 | 58 | 77 | 82 |
| | 20 | 227 | 178 | 185 | | 20 | 61 | 60 | 94 |
| 10/21 | 0 | 185 | 130 | 142 | 10/21 | 0 | 166 | 67 | 112 |
| | 2.5 | 180 | 150 | 157 | | 2.5 | 167 | 150 | 106 |
| | 10 | 160 | 154 | 165 | | 10 | 55 | 107 | 82 |
| | 20 | 222 | 163 | 168 | | 20 | 63 | 71 | 82 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 377 | 49 | 110 | 4/28 | 0 | 151 | 120 | 143 |
| | 2.5 | 160 | 162 | 167 | | 2.5 | 169 | 148 | 158 |
| | 10 | 198 | 84 | 89 | | 10 | 174 | 158 | 169 |
| | 20 | 79 | 158 | 84 | | 20 | 188 | 160 | 144 |
| 6/26 | 0 | 222 | 94 | 149 | 7/17 | 0 | 279 | 228 | 266 |
| | 2.5 | 259 | 162 | 186 | | 2.5 | 262 | 255 | 246 |
| | 10 | 86 | 150 | 99 | | 10 | 322 | 241 | 237 |
| | 20 | 102 | 100 | 144 | | 20 | 328 | 254 | 238 |
| 8/21 | 0 | 177 | 67 | 147 | 9/04 | 0 | 191 | 179 | 213 |
| | 2.5 | 179 | 166 | 135 | | 2.5 | 225 | 217 | 202 |
| | 10 | 103 | 99 | 86 | | 10 | 234 | 211 | 238 |
| | 20 | 97 | 85 | 118 | | 20 | 256 | 209 | 197 |
| 10/15 | 0 | 180 | 64 | 135 | 10/15 | 0 | 227 | 188 | 187 |
| | 2.5 | 188 | 155 | 126 | | 2.5 | 221 | 221 | 193 |
| | 10 | 91 | 111 | 72 | | 10 | 223 | 194 | 174 |
| | 20 | 86 | 72 | 100 | | 20 | 274 | 210 | 189 |

## Appendix C9. Nitrate Nitrogen (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 40.1 | 20.6 | 10.0 |
| | 2.5 | 36.7 | 23.0 | 54.2 |
| | 10 | 20.1 | 32.1 | 77.4 |
| | 20 | 23.9 | 36.2 | 31.9 |
| 6/13 | 0 | 8.4 | 6.8 | 3.4 |
| | 2.5 | 11.9 | 26.5 | 12.3 |
| | 10 | 32.8 | 19.9 | 9.6 |
| | 20 | 24.3 | 23.4 | 12.8 |
| 8/13 | 0 | 8.1 | 16.7 | 25.5 |
| | 2.5 | 12.6 | 12.1 | 7.5 |
| | 10 | 8.9 | 7.9 | 8.2 |
| | 20 | 9.2 | 8.9 | 7.8 |
| 10/21 | 0 | 5.2 | 4.8 | 4.8 |
| | 2.5 | 5.1 | 5.5 | 4.7 |
| | 10 | 5.6 | 5.9 | 8.0 |
| | 20 | 4.4 | 4.8 | 4.8 |
| **1987** | | | | |
| 4/28 | 0 | 14.3 | 5.8 | 7.7 |
| | 2.5 | 8.8 | 5.3 | 17.7 |
| | 10 | 11.5 | 7.3 | 20.9 |
| | 20 | 11.4 | 17.5 | 12.2 |
| 6/26 | 0 | 17.3 | 10.0 | 13.9 |
| | 2.5 | 31.7 | 21.2 | 40.9 |
| | 10 | 10.0 | 17.0 | 29.6 |
| | 20 | 9.8 | 6.2 | 36.8 |
| 8/21 | 0 | 15.0 | 4.6 | 9.0 |
| | 2.5 | 11.0 | 8.9 | 15.1 |
| | 10 | 4.5 | 14.3 | 8.7 |
| | 20 | 5.2 | 6.3 | 15.8 |
| 10/15 | 0 | 4.0 | 1.7 | 4.0 |
| | 2.5 | 4.6 | 8.2 | 6.5 |
| | 10 | 1.8 | 3.7 | 4.2 |
| | 20 | 4.8 | 4.2 | 2.8 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 4.1 | 1.4 | 3.4 |
| | 2.5 | 2.3 | 1.8 | 3.0 |
| | 10 | 1.4 | 1.6 | 3.0 |
| | 20 | 1.6 | 1.2 | 3.0 |
| 7/18 | 0 | 4.6 | 1.7 | 2.7 |
| | 2.5 | 4.3 | 3.2 | 3.0 |
| | 10 | 1.4 | 2.3 | 2.4 |
| | 20 | 1.9 | 2.0 | 3.9 |
| 8/29 | 0 | 3.0 | 1.6 | 2.4 |
| | 2.5 | 3.1 | 2.6 | 3.2 |
| | 10 | 2.3 | 2.0 | 3.8 |
| | 20 | 2.0 | 2.0 | 4.0 |
| 10/21 | 0 | 4.0 | 2.4 | 3.1 |
| | 2.5 | 3.6 | 3.6 | 4.0 |
| | 10 | 2.8 | 3.2 | 5.2 |
| | 20 | 2.9 | 3.4 | 4.2 |
| **1987** | | | | |
| 4/28 | 0 | 8.0 | 5.2 | 5.6 |
| | 2.5 | 6.1 | 4.7 | 5.4 |
| | 10 | 6.1 | 6.2 | 4.6 |
| | 20 | 5.1 | 6.2 | 5.7 |
| 7/17 | 0 | 7.2 | 5.3 | 4.7 |
| | 2.5 | 8.1 | 6.0 | 5.2 |
| | 10. | 9.0 | 7.2 | 5.7 |
| | 20 | 8.0 | 5.9 | 6.8 |
| 9/04 | 0 | 6.5 | 7.1 | 6.8 |
| | 2.5 | 4.9 | 5.4 | 4.7 |
| | 10 | 7.0 | 8.2 | 6.6 |
| | 20 | 7.8 | 7.0 | 5.2 |
| 10/15 | 0 | 4.4 | 7.9 | 7.2 |
| | 2.5 | 6.2 | **6.9** | 3.7 |
| | 10 | 5.9 | 4.7 | 7.2 |
| | 20 | **6.6** | 3.7 | 6.5 |

## Appendix C10. Total Kjeldahl Nitrogen (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 2580 | 1870 | 2280 | 5/21 | 0 | 1580 | 792 | 1340 |
| | 2.5 | 2680 | 2280 | 2360 | | 2.5 | 1710 | 1550 | 1200 |
| | 10 | 2450 | 2320 | 2330 | | 10 | 939 | 1160 | 981 |
| | 20 | 2910 | 2090 | 2020 | | 20 | 1210 | 920 | 1020 |
| 6/13 | 0 | 2370 | 1940 | 2390 | 7/18 | 0 | 2780 | 586 | 1240 |
| | 2.5 | 2170 | 2190 | 2100 | | 2.5 | 2360 | 1900 | 1540 |
| | 10 | 2300 | 2310 | 2060 | | 10 | 939 | 886 | 1060 |
| | 20 | 2700 | 2230 | 2260 | | 20 | 1110 | 1090 | 1070 |
| 8/13 | 0 | 2460 | 1970 | 2350 | 8/29 | 0 | 1620 | 518 | 1530 |
| | 2.5 | 2460 | 2280 | 2270 | | 2.5 | 1640 | 1540 | 1460 |
| | 10 | 2240 | 2040 | 2340 | | 10 | 583 | 963 | 1150 |
| | 20 | 2640 | 2140 | 2330 | | 20 | 941 | 856 | 1220 |
| 10/21 | 0 | 2260 | 1820 | 2330 | 10/21 | 0 | 2040 | 849 | 1470 |
| | 2.5 | 2200 | 2020 | 2290 | | 2.5 | 1080 | 1650 | 1290 |
| | 10 | 2370 | 2100 | 2120 | | 20 | 961 | 1190 | 770 |
| | 20 | 2620 | 2110 | 2240 | | 20 | 1030 | 883 | 1250 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 1910 | 1580 | 1280 | 4/28 | 0 | 2170 | 1890 | 2120 |
| | 2.5 | 1810 | 790 | 1450 | | 2.5 | 2740 | 1890 | 2170 |
| | 10 | 1010 | 1010 | 1020 | | 10 | 2150 | 1910 | 2020 |
| | 20 | 822 | 1080 | 1310 | | 20 | 2320 | 2150 | 2130 |
| 6/26 | 0 | 2220 | 800 | 1860 | 7/17 | 0 | 2600 | 2030 | 2580 |
| | 2.5 | 2250 | 1760 | 1750 | | 2.5 | 2580 | 2330 | 2400 |
| | 10 | 1110 | 1190 | 1310 | | 10 | 2720 | 2230 | 2060 |
| | 20 | 1360 | 1160 | 1520 | | 20 | 2920 | 2320 | 2470 |
| 8/21 | 0 | 1920 | 669 | 1220 | 9/04 | 0 | 2180 | 1580 | 2160 |
| | 2.5 | 1820 | 1520 | 1320 | | 2.5 | 2080 | 2150 | 2010 |
| | 10 | 794 | 845 | 757 | | 10 | 2250 | 2100 | 2060 |
| | 20 | 680 | 597 | 1020 | | 20 | 2440 | 2060 | 2100 |
| 10/15 | 0 | 1650 | 709 | 1300 | 10/15 | 0 | 2100 | 1720 | 2070 |
| | 2.5 | 1590 | 1290 | 1310 | | 2.5 | 2100 | 2050 | 1960 |
| | 10 | 813 | 1020 | 876 | | 10 | 2040 | 1870 | 1850 |
| | 20 | 820 | 800 | 1050 | | 20 | 2370 | 1890 | 1890 |

Appendix C11. Total Nitrogen (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 2590 | 1890 | 2290 | 5/21 | 0 | 1590 | 794 | 1340 |
| | 2.5 | 2720 | 2300 | 2420 | | 2.5 | 1710 | 1560 | 1200 |
| | 10 | 2470 | 2350 | 2410 | | 10 | 940 | 1160 | 984 |
| | 20 | 2940 | 2110 | 2050 | | 20 | 1210 | 920 | 1020 |
| 6/13 | 0 | 2380 | 1950 | 2430 | 7/18 | 0 | 2780 | 588 | 1240 |
| | 2.5 | 2180 | 2220 | 2110 | | 2.5 | 2370 | 1900 | 1540 |
| | 10 | 2340 | 2330 | 2070 | | 10 | 940 | 888 | 1070 |
| | 20 | 2730 | 2250 | 2270 | | 20 | 1110 | 1090 | 1070 |
| 8/13 | 0 | 2470 | 1990 | 2380 | 8/29 | 0 | 1630 | 520 | 1530 |
| | 2.5 | 2480 | 2290 | 2280 | | 2.5 | 1650 | 1540 | 1470 |
| | 10 | 2250 | 2050 | 2350 | | 10 | 585 | 965 | 1160 |
| | 20 | 2650 | 2150 | 2340 | | 20 | 943 | 858 | 1220 |
| 10/21 | 0 | 2270 | 1820 | 2340 | 10/21 | 0 | 2050 | 851 | 1480 |
| | 2.5 | 2210 | 2030 | 2300 | | 2.5 | 1080 | 1650 | 1300 |
| | 10 | 2370 | 2110 | 2130 | | 10 | 964 | 1190 | 773 |
| | 20 | 2630 | 2110 | 2250 | | 20 | 1030 | 887 | 1260 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 1930 | 1590 | 1290 | 4/28 | 0 | 2190 | 1890 | 2130 |
| | 2.5 | 1820 | 790 | 1470 | | 2.5 | 2750 | 1900 | 2180 |
| | 10 | 1020 | 1020 | 1040 | | 10 | 2160 | 1920 | 2020 |
| | 20 | 833 | 1100 | 1320 | | 20 | 2330 | 2160 | 2140 |
| 6/26 | 0 | 2240 | 810 | 1880 | 7/17 | 0 | 2610 | 2040 | 2590 |
| | 2.5 | 2280 | 1780 | 1790 | | 2.5 | 2590 | 2340 | 2410 |
| | 10 | 1120 | 1210 | 1350 | | 10 | 2730 | 2340 | 2070 |
| | 20 | 1370 | 1170 | 1560 | | 20 | 2930 | 2330 | 2480 |
| 8/21 | 0 | 1940 | 674 | 1230 | 9/04 | 0 | 2190 | 1590 | 2170 |
| | 2.5 | 1830 | 1530 | 1330 | | 2.5 | 2090 | 2160 | 2020 |
| | 10 | 799 | 860 | 766 | | 10 | 2260 | 2110 | 2070 |
| | 20 | 685 | 603 | 1030 | | 20 | 2450 | 2070 | 2110 |
| 10/15 | 0 | 1650 | 711 | 1300 | 10/15 | 0 | 2110 | 1730 | 2180 |
| | 2.5 | 1600 | 1300 | 1320 | | 2.5 | 2110 | 2060 | 1970 |
| | 10 | 815 | 1030 | 880 | | 10 | 2050 | 1880 | 1860 |
| | 20 | 825 | 804 | 1050 | | 20 | 2380 | 1900 | 1900 |

## Appendix C12. Bray P-1 (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots | | | Date | Application Rate, t/a | Soybean Plots | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Rep 1L | Rep 2 | Rep 3 | | | Rep 1 | Rep 2 | Rep 3 |
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 12 | 12 | 4.8 | 5/21 | 0 | 17 | 14 | 18 |
| | 2.5 | 18 | 7.1 | 9.4 | | 2.5 | 14 | 18 | 23 |
| | 10 | 16 | 20 | 10 | | 10 | 19 | 18 | 17 |
| | 20 | 13 | 16 | 11 | | 20 | 25 | 19 | 54 |
| 6/13 | 0 | 15 | 20 | 4.2 | 7/18 | 0 | 42 | 18 | 17 |
| | 2.5 | 9.7 | 17 | 5.9 | | 2.5 | 28 | 40 | 34 |
| | 10 | 13 | 27 | 11 | | 10 | 20 | 25 | 29 |
| | 20 | 20 | 24 | 13 | | 20 | 16 | 18 | 20 |
| 8/13 | 0 | 18 | 16 | 4.5 | 8/29 | 0 | 24 | 23 | 21 |
| | 2.5 | 16 | 17 | 9.8 | | 2.5 | 17 | 15 | 28 |
| | 10 | 21 | 16 | 15 | | 10 | 24 | 18 | 23 |
| | 20 | 21 | 19 | 15 | | 20 | 33 | 16 | 26 |
| 10/21 | 0 | 17 | 17 | 4.6 | 10/21 | 0 | 22 | 17 | 18 |
| | 2.5 | 16 | 17 | 8.2 | | 2.5 | 23 | 21 | 31 |
| | 10 | 17 | 21 | 11 | | 10 | 19 | 28 | 20 |
| | 20 | 24 | 25 | 11 | | 20 | 23 | 22 | 37 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 15 | 11 | 7.7 | 4/28 | 0 | 13 | 11 | 4.1 |
| | 2.5 | 12 | 12 | 13 | | 2.5 | 9.2 | 9.2 | 8.2 |
| | 10 | 8.9 | 13 | 9.2 | | 10 | 8.4 | 17 | 9.7 |
| | 20 | 12 | 18 | 10 | | 20 | 12 | 20 | 8.3 |
| 6/26 | 0 | 16 | 12 | 11 | 7/17 | 0 | 17 | 8.3 | 6.2 |
| | 2.5 | 16 | 12 | 25 | | 2.5 | 18 | 13 | 11 |
| | 10 | 20 | 13 | 11 | | 10 | 15 | 11 | 14 |
| | 20 | 20 | 12 | 20 | | 20 | 17 | 26 | 9.0 |
| 8/21 | 0 | 12 | 8.3 | 16 | 9/04 | 0 | 14 | 14 | 5.7 |
| | 2.5 | 13 | 12 | 10 | | 2.5 | 11 | 12 | 8.0 |
| | 10 | 13 | 11 | 12 | | 10 | 13 | 21 | 12 |
| | 20 | 12 | 10 | 20 | | 20 | 18 | 24 | 14 |
| 10/15 | 0 | 14 | 12 | 11 | 10/15 | 0 | 14 | 13 | 6.0 |
| | 2.5 | 14 | 13 | 19 | | 2.5 | 16 | 11 | 11 |
| | 10 | 18 | 9.8 | 6.7 | | 10 | 11 | 19 | 17 |
| | 20 | 18 | 14 | 16 | | 20 | 19 | 18 | 12 |

Appendix C13. Total Phosphorus (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 500 | 402 | 796 | 5/21 | 0 | 746 | 392 | 503 |
| | 2.5 | 508 | 379 | 603 | | 2.5 | 597 | 730 | 642 |
| | 10 | 537 | 477 | 472 | | 10 | 545 | 464 | 623 |
| | 20 | 618 | 616 | 696 | | 20 | 491 | 428 | 606 |
| 6/13 | 0 | 645 | 569 | 770 | 7/18 | 0 | 700 | 508 | 617 |
| | 2.5 | 573 | 581 | 625 | | 2.5 | 676 | 636 | 607 |
| | 10 | 577 | 626 | 646 | | 10 | 516 | 505 | 712 |
| | 20 | 895 | 708 | 813 | | 20 | 492 | 475 | 550 |
| 8/13 | 0 | 602 | 515 | 789 | 8/29 | 0 | 636 | 567 | 506 |
| | 2.5 | 562 | 574 | 642 | | 2.5 | 573 | 570 | 636 |
| | 10 | 527 | 579 | 584 | | 10 | 477 | 450 | 653 |
| | 20 | 815 | 640 | 653 | | 20 | 432 | 452 | 533 |
| 10/21 | 0 | 618 | 533 | 771 | 10/21 | 0 | 624 | 506 | 439 |
| | 2.5 | 410 | 539 | 622 | | 2.5 | 597 | 591 | 610 |
| | 10 | 587 | 530 | 589 | | 10 | 530 | 486 | 341 |
| | 20 | 781 | 640 | 696 | | 20 | 394 | 429 | 426 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 554 | 539 | 448 | 4/28 | 0 | 561 | 652 | 693 |
| | 2.5 | 585 | 554 | 633 | | 2.5 | 570 | 533 | 492 |
| | 10 | 448 | 447 | 606 | | 10 | 546 | 675 | 486 |
| | 20 | 454 | 565 | 504 | | 20 | 713 | 614 | 618 |
| 6/26 | 0 | 570 | 526 | 516 | 7/17 | 0 | 529 | 601 | 849 |
| | 2.5 | 601 | 582 | 586 | | 2.5 | 643 | 537 | 472 |
| | 10 | 504 | 491 | 656 | | 10 | 592 | 618 | 623 |
| | 20 | 486 | 487 | 544 | | 20 | 662 | 643 | 768 |
| 8/21 | 0 | 688 | 793 | 586 | 9/04 | 0 | 550 | 601 | 677 |
| | 2.5 | 632 | 662 | 720 | | 2.5 | 544 | 555 | 669 |
| | 10 | 536 | 574 | 676 | | 10 | 602 | 657 | 635 |
| | 20 | 537 | 601 | 627 | | 20 | 826 | 706 | 716 |
| 10/15 | 0 | 595 | 584 | 486 | 10/15 | 0 | 725 | 599 | 876 |
| | 2.5 | 620 | 558 | 613 | | 2.5 | 676 | 581 | 706 |
| | 10 | 521 | 452 | 589 | | 10 | 696 | 692 | 697 |
| | 20 | 540 | 464 | 515 | | 20 | 702 | 643 | 771 |

## Appendix C14. Potassium (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 860 | 780 | 650 | 5/21 | 0 | 700 | 790 | 710 |
| | 2.5 | 790 | 800 | 800 | | 2.5 | 860 | 1080 | 1010 |
| | 10 | 790 | 880 | 660 | | 10 | 740 | 830 | 720 |
| | 20 | 800 | 960 | 690 | | 20 | 820 | 770 | 860 |
| 6/13 | 0 | 610 | 820 | 750 | 7/18 | 0 | 1060 | 600 | 530 |
| | 2.5 | 720 | 830 | 760 | | 2.5 | 610 | 840 | 610 |
| | 10 | 830 | 850 | 710 | | 10 | 630 | 880 | 580 |
| | 20 | 670 | 720 | 670 | | 20 | 760 | 790 | 540 |
| 8/13 | 0 | 700 | 420 | 480 | 8/29 | 0 | 760 | 680 | 730 |
| | 2.5 | 630 | 520 | 420 | | 2.5 | 560 | 670 | 640 |
| | 10 | 540 | 460 | 560 | | 10 | 780 | 670 | 590 |
| | 20 | 620 | 480 | 570 | | 20 | 630 | 640 | 610 |
| 10/21 | 0 | 650 | 630 | 660 | 10/21 | 0 | 860 | 790 | 560 |
| | 2.5 | 620 | 670 | 620 | | 2.5 | 800 | 820 | 880 |
| | 10 | 630 | 670 | 650 | | 10 | 670 | 580 | 580 |
| | 20 | 730 | 600 | 630 | | 20 | 900 | 720 | 570 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 1010 | 400 | 1586 | 4/28 | 0 | 821 | 767 | 804 |
| | 2.5 | 1000 | 377 | 399 | | 2.5 | 800 | 798 | 599 |
| | 10 | 196 | 993 | 1381 | | 10 | 807 | 823 | 403 |
| | 20 | 1592 | 604 | 798 | | 20 | 997 | 397 | 782 |
| 6/26 | 0 | 950 | 1040 | 1220 | 7/17 | 0 | 920 | 740 | 780 |
| | 2.5 | 985 | 1080 | 930 | | 2.5 | 830 | 830 | 940 |
| | 10 | 910 | 740 | 880 | | 10 | 850 | 1000 | 970 |
| | 20 | 1445 | 850 | 1170 | | 20 | 860 | 800 | 1000 |
| 8/21 | 0 | 696 | 700 | 673 | 9/04 | 0 | 731 | 513 | 765 |
| | 2.5 | 755 | 757 | 760 | | 2.5 | 742 | 681 | 643 |
| | 10 | 725 | 704 | 653 | | 10 | 648 | 713 | 655 |
| | 20 | 731 | 737 | 738 | | 20 | 712 | 696 | 722 |
| 10/15 | 0 | 759 | 926 | 559 | 10/15 | 0 | 717 | 621 | 613 |
| | 2.5 | 746 | 763 | 892 | | 2.5 | 724 | 635 | 578 |
| | 10 | 859 | 841 | 711 | | 10 | 592 | 729 | 618 |
| | 20 | 734 | 717 | 784 | | 20 | 766 | 570 | 625 |

## Appendix C15. Total Aluminum (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 9300 | 9400 | 9300 |
| | 2.5 | 10600 | 10200 | 10400 |
| | 10 | 10500 | 9900 | 9700 |
| | 20 | 9600 | 10500 | 9100 |
| 6/13 | 0 | 10000 | 10100 | 10600 |
| | 2.5 | 10500 | 10200 | 11100 |
| | 10 | 8500 | 10300 | 11400 |
| | 20 | 11400 | 10300 | 10600 |
| 8/13 | 0 | 11000 | 10000 | 10900 |
| | 2.5 | 9200 | 9800 | 10200 |
| | 10 | 10100 | 10000 | 10100 |
| | 20 | 10700 | 10900 | 10900 |
| 10/21 | 0 | 9600 | 9800 | 9800 |
| | 2.5 | 10300 | 10600 | 10500 |
| | 10 | 10300 | 10400 | 10400 |
| | 20 | 10900 | 10500 | 10100 |
| **1987** | | | | |
| 4/28 | 0 | 10700 | 8800 | 10400 |
| | 2.5 | 11100 | 10000 | 10100 |
| | 10 | 10100 | 9500 | 6800 |
| | 20 | 9600 | 10600 | 8200 |
| 6/26 | 0 | 14400 | 12700 | 18200 |
| | 2.5 | 14500 | 15900 | 12400 |
| | 10 | 13200 | 12300 | 12300 |
| | 20 | 20700 | 12100 | 15200 |
| 8/21 | 0 | 10500 | 11200 | 12200 |
| | 2.5 | 11100 | 11700 | 10800 |
| | 10 | 11800 | 11200 | 9800 |
| | 20 | 11700 | 11600 | 10500 |
| 10/15 | 0 | 11400 | 10200 | 12800 |
| | 2.5 | 11700 | 12400 | 12100 |
| | 10 | 12400 | 12300 | 9800 |
| | 20 | 11300 | 11600 | 11900 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 9300 | 9300 | 10700 |
| | 2.5 | 10200 | 9900 | 9800 |
| | 10 | 9100 | 10000 | 7400 |
| | 20 | 10600 | 9500 | 10400 |
| 7/18 | 0 | 10300 | 10100 | 10500 |
| | 2.5 | 10200 | 10200 | 11200 |
| | 10 | 10400 | 10800 | 9600 |
| | 20 | 10700 | 10200 | 9500 |
| 8/29 | 0 | 11300 | 10200 | 11500 |
| | 2.5 | 11000 | 10700 | 10400 |
| | 10 | 10800 | 11000 | 9500 |
| | 20 | 10400 | 10100 | 9800 |
| 10/21 | 0 | 11300 | 10500 | 11400 |
| | 2.5 | 11500 | 10400 | 10700 |
| | 10 | 9800 | 11800 | 9100 |
| | 20 | 11300 | 11500 | 10000 |
| **1987** | | | | |
| 4/28 | 0 | 9300 | 8500 | 8900 |
| | 2.5 | 9900 | 8400 | 8700 |
| | 10 | 9400 | 9400 | 8800 |
| | 20 | 9300 | 8200 | 8800 |
| 7/17 | 0 | 10800 | 9500 | 10400 |
| | 2.5 | 9600 | 11000 | 13100 |
| | 10 | 10300 | 11000 | 14400 |
| | 20 | 10300 | 11800 | 13900 |
| 9/04 | 0 | 9900 | 9900 | 10900 |
| | 2.5 | 11500 | 10800 | 9300 |
| | 10 | 10800 | 10300 | 11000 |
| | 20 | 11100 | 11700 | 11200 |
| 10/15 | 0 | 10200 | 9600 | 9100 |
| | 2.5 | 10200 | 9200 | 10500 |
| | 10 | 9800 | 11000 | 12000 |
| | 20 | 11400 | 10300 | 9300 |

## Appendix C16. Boron (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 0.48 | 0.28 | 0.19 | 5/21 | 0 | 0.46 | 0.28 | 0.54 |
| | 2.5 | 0.36 | 0.27 | 0.19 | | 2.5 | 0.42 | 0.23 | 0.28 |
| | 10 | 0.38 | 0.25 | 0.25 | | 10. | 0.28 | 0.21 | 0.50 |
| | 20 | 0.36 | 0.17 | 0.35 | | 20 | 0.22 | 0.22 | 0.47 |
| 6/13 | 0 | 0.49 | 0.35 | 0.38 | 7/18 | 0 | 0.70 | 0.21 | 0.21 |
| | 2.5 | 0.46 | 0.38 | 0.60 | | 2.5 | 0.46 | 0.29 | 0.31 |
| | 10 | 0.59 | 0.44 | 0.45 | | 10 | 0.27 | 0.21 | 0.28 |
| | 20 | 0.39 | 0.43 | 0.44 | | 20 | 0.28 | 0.19 | 0.19 |
| 8/13 | 0 | 0.45 | 0.27 | 0.34 | 8/29 | 0 | 0.64 | 0.14 | 0.34 |
| | 2.5 | 0.29 | 0.53 | 0.36 | | 2.5 | 0.42 | 0.28 | 0.18 |
| | 10 | 0.55 | 0.35 | 0.32 | | 10 | 0.19 | 0.36 | 0.36 |
| | 20 | 0.43 | 0.50 | 0.34 | | 20 | 0.21 | 0.18 | 0.26 |
| 10/21 | 0 | 0.59 | 0.33 | 0.41 | 10/21 | 0 | 0.38 | 0.15 | 0.27 |
| | 2.5 | 0.48 | 0.53 | 0.36 | | 2.5 | 0.36 | 0.20 | 0.08 |
| | 10 | 0.48 | 0.37 | 0.24 | | 10 | 0.20 | 0.09 | 0.19 |
| | 20 | 0.41 | 0.39 | 0.32 | | 20 | 0.12 | 0.05 | 0.10 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 0.62 | 0.37 | 0.31 | 4/28 | 0 | 1.47 | 0.65 | 0.51 |
| | 2.5 | 0.60 | 0.53 | 0.25 | | 2.5 | 1.45 | 0.63 | 0.49 |
| | 10 | 0.51 | 0.33 | 0.20 | | 10 | 0.82 | 0.58 | 0.54 |
| | 20 | 0.31 | 0.37 | 0.24 | | 20 | 0.73 | 0.41 | 0.49 |
| 6/26 | 0 | 0.20 | 0.30 | 0.10 | 7/17 | 0 | 0.10 | 0.33 | 0.48 |
| | 2.5 | 0.20 | 0.30 | 0.10 | | 2.5 | 0.30 | 0.33 | 0.32 |
| | 10 | 0.20 | 0.20 | 0.20 | | 10 | 0.20 | 0.36 | 0.32 |
| | 20 | 0.30 | 0.30 | 0.20 | | 20 | 0.30 | 0.34 | 0.24 |
| 8/21 | 0 | 0.31 | 0.24 | 0.16 | 9/04 | 0 | 0.32 | 0.38 | 0.39 |
| | 2.5 | 0.29 | 0.26 | 0.20 | | 2.5 | 0.41 | 0.52 | 0.41 |
| | 10 | 0.25 | 0.29 | 0.13 | | 10 | 0.38 | 0.61 | 0.61 |
| | 20 | 0.29 | 0.17 | 0.21 | | 20 | 0.34 | 0.58 | 0.42 |
| 10/15 | 0 | 0.47 | 0.27 | 0.21 | 10/15 | 0 | 0.41 | 0.27 | 0.29 |
| | 2.5 | 0.43 | 0.40 | 0.17 | | 2.5 | 0.44 | 0.35 | 0.35 |
| | 10 | 0.41 | 0.34 | 0.27 | | 10 | 0.48 | 0.42 | 0.35 |
| | 20 | 0.34 | 0.31 | 0.23 | | 20 | 0.43 | 0.41 | 0.34 |

## Appendix C17. Cadmium (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 0.78 | 0.99 | 0.28 | 5/21 | 0 | 0.76 | 0.87 | <0.10 |
| | 2.5 | <0.10 | 0.29 | 0.39 | | 2.5 | 0.28 | 0.99 | 0.39 |
| | 10 | 1.33 | 0.20 | <0.10 | | 10 | 0.19 | 0.40 | 0.79 |
| | 20 | 0.80 | <0.10 | <0.10 | | 20 | | 1.00 | 0.68 |
| 6/13 | 0 | <0.10 | <0.10 | <0.10 | 7/18 | 0 | 0.29 | 1.00 | 1.59 |
| | 2.5 | 0.10 | <0.10 | <0.10 | | 2.5 | <0.10 | <0.10 | 1.36 |
| | 10 | 0.17 | <0.10 | <0.10 | | 10 | <0.10 | 0.66 | 1.88 |
| | 20 | 0.89 | <0.10 | <0.10 | | 20 | <0.10 | 1.42 | 0.56 |
| 8/13 | 0 | <0.10 | 0.10 | 1.29 | 8/29 | 0 | 1.35 | 1.58 | 1.50 |
| | 2.5 | 0.29 | 1.85 | 1.75 | | 2.5 | 0.77 | 1.47 | 2.32 |
| | 10 | <0.10 | 1.71 | 1.82 | | 10 | 0.93 | 0.78 | 1.58 |
| | 20 | <0.10 | 0.99 | 0.88 | | 20 | 1.59 | 1.32 | 0.78 |
| 10/21 | 0 | 1.25 | 0.49 | 0.87 | 10/21 | 0 | 0.87 | 0.76 | 0.77 |
| | 2.5 | 1.36 | 0.49 | 0.78 | | 2.5 | <0.10 | <0.10 | 0.60 |
| | 10 | 0.90 | <0.10 | 1.70 | | 10 | <0.10 | <0.10 | 0.10 |
| | 20 | 0.80 | 1.41 | 0.99 | | 20 | 0.68 | 0.29 | <0.10 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 0.40 | 0.50 | 0.20 | 4/28 | 0 | 0.82 | 1.05 | 0.80 |
| | 2.5 | 0.50 | 0.57 | 0.40 | | 2.5 | 1.00 | 0.40 | 0.80 |
| | 10 | 1.08 | 0.50 | 0.89 | | 10 | 0.91 | 1.34 | 0.60 |
| | 20 | 0.70 | 0.60 | 0.70 | | 20 | 0.90 | 0.50 | 1.00 |
| 6/28 | 0 | <0.10 | 0.50 | 0.20 | 7/17 | 0 | 0.30 | 0.40 | 0.30 |
| | 2.5 | 0.20 | 0.50 | 0.50 | | 2.5 | 0.50 | 0.70 | 0.50 |
| | 10 | 0.15 | 0.60 | 0.90 | | 10 | 0.40 | 0.10 | 0.30 |
| | 20 | 0.70 | 0.70 | 0.30 | | 20 | 0.10 | 0.10 | 0.20 |
| 8/21 | 0 | 0.39 | 0.60 | 0.46 | 9/04 | 0 | 0.29 | 0.39 | 0.39 |
| | 2.5 | 0.60 | 0.50 | 0.69 | | 2.5 | 0.59 | 0.49 | 1.09 |
| | 10 | 0.49 | 0.77 | 1.27 | | 10 | 0.30 | 0.43 | 0.90 |
| | 20 | 0.69 | 0.53 | 1.09 | | 20 | 0.58 | 0.20 | 0.50 |
| 10/15 | 0 | 0.56 | 0.39 | 0.30 | 10/15 | 0 | 0.40 | 0.59 | 0.70 |
| | 2.5 | 0.69 | 0.40 | 0.59 | | 2.5 | 0.69 | 0.50 | 0.89 |
| | 10 | 0.39 | 0.79 | 0.59 | | 10 | 0.60 | 0.99 | 0.60 |
| | 20 | 0.60 | 0.89 | 0.89 | | 20 | 0.90 | 0.30 | 0.79 |

## Appendix C18. Calcium (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 2490 | 2490 | 5890 |
| | 2.5 | 2680 | 2600 | 3340 |
| | 10 | 2860 | 2450 | 2800 |
| | 20 | 3310 | 4520 | 3490 |
| 6/13 | 0 | 2480 | 2290 | 9500 |
| | 2.5 | 2800 | 2460 | 3910 |
| | 10 | 2550 | 2460 | 3090 |
| | 20 | 4320 | 2520 | 3370 |
| 8/13 | 0 | 2590 | 2220 | 3840 |
| | 2.5 | 25290 | 2400 | 3620 |
| | 10 | 3090 | 2340 | 3320 |
| | 20 | 3510 | 2440 | 4060 |
| 10/21 | 0 | 2410 | 2240 | 4790 |
| | 2.5 | 2550 | 2310 | 3310 |
| | 10 | 2550 | 2310 | 3090 |
| | 20 | 4290 | 2510 | 3760 |
| **1987** | | | | |
| 4/28 | 0 | 3430 | 2200 | 2380 |
| | 2.5 | 3400 | 1890 | 9780 |
| | 10 | 2750 | 2580 | 23300 |
| | 20 | 3180 | 2820 | 9370 |
| 6/26 | 0 | 2990 | 2900 | 2930 |
| | 2.5 | 3480 | 3040 | 5070 |
| | 10 | 2980 | 2410 | 28700 |
| | 20 | 4570 | 3230 | 4590 |
| 8/21 | 0 | 3080 | 2360 | 2360 |
| | 2.5 | 2400 | 2090 | 5150 |
| | 10 | 1320 | 1850 | 20000 |
| | 20 | 2000 | 3050 | 7470 |
| 10/15 | 0 | 2720 | 2800 | 2390 |
| | 2.5 | 2950 | 2590 | 4590 |
| | 10 | 2850 | 2490 | 20900 |
| | 20 | 3060 | 3030 | 5830 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 2530 | 2360 | 1910 |
| | 2.5 | 2730 | 2950 | 8560 |
| | 10 | 2320 | 2050 | 29150 |
| | 20 | 2590 | 2130 | 6080 |
| 7/18 | 0 | 2550 | 2000 | 2150 |
| | 2.5 | 2620 | 2260 | 4430 |
| | 10 | 1940 | 1850 | 19130 |
| | 20 | 2110 | 2000 | 8860 |
| 8/29 | 0 | 2870 | 2640 | 2710 |
| | 2.5 | 2130 | 2490 | 6810 |
| | 10 | 2850 | 2260 | 2340 |
| | 20 | 2900 | 2790 | 5340 |
| 10/21 | 0 | 2590 | 2820 | 2370 |
| | 2.5 | 3000 | 2570 | 7080 |
| | 10 | 2270 | 2690 | 21900 |
| | 20 | 2730 | 2960 | 5830 |
| **1987** | | | | |
| 4/21 | 0 | 3490 | 3640 | 6830 |
| | 2.5 | 3600 | 3790 | 5190 |
| | 10 | 3430 | 4110 | 4630 |
| | 20 | 4790 | 4170 | 5210 |
| 7/17 | 0 | 3870 | 3120 | 6750 |
| | 2.5 | 3300 | 3590 | 4370 |
| | 10 | 4030 | 3240 | 4180 |
| | 20 | 5080 | 4380 | 5690 |
| 9/04 | 0 | 1900 | 1720 | 7040 |
| | 2.5 | 1670 | 2170 | 3430 |
| | 10 | 2770 | 2530 | 3470 |
| | 20 | 3730 | 3260 | 4510 |
| 10/15 | 0 | 2370 | 2230 | 5560 |
| | 2.5 | 2650 | 2070 | 3700 |
| | 10 | 2530 | 2320 | 5080 |
| | 20 | 3550 | 2890 | 4360 |

Appendix C19. Chromium (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 12 | 17 | 16 | 5/21 | 0 | 16 | 17 | 17 |
| | 2.5 | 15 | 17 | 19 | | 2.5 | 18 | 18 | 18 |
| | 10 | 17 | 16 | 18 | | 10 | 19 | 18 | 16 |
| | 20 | 17 | 17 | 15 | | 20 | 21 | 15 | 16 |
| 6/13 | 0 | 16 | 17 | 17 | 7/18 | 0 | 15 | 18 | 18 |
| | 2.5 | 18 | 17 | 16 | | 2.5 | 14 | 16 | 20 |
| | 10 | 14 | 15 | 18 | | 10 | 20 | 19 | 18 |
| | 20 | 18 | 16 | 18 | | 20 | 19 | 19 | 16 |
| 8/13 | 0 | 18 | 17 | 17 | 8/29 | 0 | 16 | 20 | 17 |
| | 2.5 | 16 | 16 | 18 | | 2.5 | 17 | 17 | 16 |
| | 10 | 16 | 13 | 15 | | 10 | 20 | 19 | 15 |
| | 20 | 15 | 16 | 18 | | 20 | 19 | 17 | 18 |
| 10/21 | 0 | 13 | 16 | 15 | 10/21 | 0 | 18 | 18 | 15 |
| | 2.5 | 16 | 17 | 14 | | 2.5 | 16 | 14 | 16 |
| | 10 | 15 | 16 | 16 | | 10 | 15 | 17 | 15 |
| | 20 | 15 | 14 | 14 | | 20 | 18 | 18 | 15 |

## Appendix C20. Copper (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 12 | 12 | 11 |
| | 2.5 | 13 | 13 | 16 |
| | 10 | 17 | 9 | 13 |
| | 20 | 11 | 10 | 11 |
| 6/13 | 0 | 11 | 15 | 14 |
| | 2.5 | 12 | 13 | 12 |
| | 10 | 8 | 12 | 13 |
| | 20 | 12 | 11 | 13 |
| 8/13 | 0 | 15 | 38 | 15 |
| | 2.5 | 17 | 16 | 15 |
| | 10 | 16 | 13 | 14 |
| | 20 | 15 | 13 | 16 |
| 10/2 | 0 | 11 | 13 | 13 |
| | 2.5 | 12 | 14 | 12 |
| | 10 | 12 | 12 | 12 |
| | 20 | 12 | 11 | 10 |
| **1987** | | | | |
| 4/28 | 0 | 14 | 17 | 15 |
| | 2.5 | 15 | 14 | 13 |
| | 10 | 17 | 15 | 12 |
| | 20 | 17 | 16 | 12 |
| 6/26 | 0 | 21 | 26 | 21 |
| | 2.5 | 17 | 23 | 18 |
| | 10 | 25 | 22 | 19 |
| | 20 | 30 | 22 | 22 |
| 8/21 | 0 | 15 | 21 | 17 |
| | 2.5 | 16 | 19 | 17 |
| | 10 | 21 | 19 | 16 |
| | 20 | 20 | 19 | 18 |
| 10/15 | 0 | 15 | 19 | 17 |
| | 2.5 | 16 | 16 | 16 |
| | 10 | 20 | 20 | 15 |
| | 20 | 20 | 19 | 17 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 11 | 17 | 13 |
| | 2.5 | 14 | 16 | 13 |
| | 10 | 16 | 15 | 11 |
| | 20 | 18 | 16 | 14 |
| 7/18 | 0 | 13 | 16 | 18 |
| | 2.5 | 13 | 12 | 17 |
| | 10 | 16 | 16 | 18 |
| | 20 | 15 | 16 | 15 |
| 8/29 | 0 | 16 | 16 | 12 |
| | 2.5 | 17 | 13 | 12 |
| | 10 | 16 | 15 | 10 |
| | 20 | 14 | 16 | 11 |
| 10/21 | 0 | 14 | 16 | 13 |
| | 2.5 | 13 | 13 | 14 |
| | 10 | 16 | 15 | 12 |
| | 20 | 15 | 16 | 12 |
| **1987** | | | | |
| 4/28 | 0 | 11 | 14 | 13 |
| | 2.5 | 13 | 15 | 12 |
| | 10 | 14 | 11 | 13 |
| | 20 | 12 | 10 | 15 |
| 7/17 | 0 | 20 | 18 | 18 |
| | 2.5 | 19 | 19 | 19 |
| | 10 | 19 | 29 | 22 |
| | 20 | 21 | 19 | 23 |
| 9/04 | 0 | 14 | 16 | 15 |
| | 2.5 | 18 | 16 | 13 |
| | 10 | 15 | 14 | 15 |
| | 20 | 15 | 15 | 16 |
| 10/15 | 0 | 12 | 15 | 15 |
| | 2.5 | 15 | 15 | 15 |
| | 10 | 16 | 13 | 16 |
| | 20 | 15 | 13 | 16 |

## Appendix C21. Iron (Total) (mg/kg) in Soils

| Date | Application Rate, t/a | Cora Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 8900 | 12100 | 11500 | 5/21 | 0 | 11600 | 15500 | 13800 |
| | 2.5 | 12000 | 11700 | 11700 | | 2.5 | 15400 | 14100 | 12400 |
| | 10 | 11500 | 10600 | 12700 | | 10 | 15700 | 14500 | 10500 |
| | 20 | 9200 | 11400 | 10300 | | 20 | 17000 | 13900 | 12300 |
| 6/13 | 0 | 10300 | 14100 | 12500 | 7/18 | 0 | 11400 | 15400 | 16600 |
| | 2.5 | 10900 | 12100 | 12300 | | 2.5 | 12200 | 9600 | 17100 |
| | 10 | 9900 | 11900 | 13300 | | 10 | 15500 | 15700 | 16000 |
| | 20 | 11700 | 11900 | 11500 | | 20 | 16200 | 16200 | 15000 |
| 8/13 | 0 | 16800 | 18700 | 16500 | 8/29 | 0 | 16100 | 20500 | 17200 |
| | 2.5 | 15600 | 14700 | 14800 | | 2.5 | 18000 | 15800 | 15300 |
| | 10 | 13900 | 16300 | 13600 | | 10 | 19700 | 18700 | 12700 |
| | 20 | 14200 | 16000 | 13800 | | 20 | 17000 | 18000 | 11300 |
| 10/21 | 0 | 10200 | 13000 | 12200 | 10/21 | 0 | 13300 | 17700 | 18400 |
| | 2.5 | 12800 | 13800 | 12000 | | 2.5 | 14100 | 11500 | 17100 |
| | 10 | 13100 | 11900 | 13400 | | 10 | 13900 | 20500 | 15500 |
| | 20 | 10100 | 11500 | 11100 | | 20 | 18100 | 19800 | 16300 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 17200 | 18600 | 18800 | 4/28 | 0 | 14600 | 16900 | 15500 |
| | 2.5 | 17800 | 16000 | 17000 | | 2.5 | 16000 | 17000 | 13600 |
| | 10 | 18900 | 16700 | 14000 | | 10 | 16100 | 15600 | 15700 |
| | 20 | 18500 | 19700 | 14400 | | 20 | 14600 | 13300 | 16000 |
| 6/26 | 0 | 17800 | 20000 | 21400 | 7/17 | 0 | 18300 | 17300 | 15800 |
| | 2.5 | 16200 | 21100 | 16500 | | 2.5 | 15500 | 16200 | 16500 |
| | 10 | 19100 | 16600 | 16100 | | 10 | 16000 | 16100 | 21200 |
| | 20 | 30000 | 17000 | 18800 | | 20 | 14400 | 17300 | 19600 |
| 8/21 | 0 | 15400 | 19700 | 17800 | 9/04 | 0 | 14200 | 14900 | 16900 |
| | 2.5 | 17900 | 14100 | 16600 | | 2.5 | 16500 | 17700 | 13000 |
| | 10 | 19100 | 19100 | 14700 | | 10 | 11000 | 15100 | 15500 |
| | 20 | 20400 | 19000 | 16200 | | 20 | 12200 | 14900 | 16100 |
| 10/15 | 0 | 15800 | 22200 | 18800 | 10/15 | 0 | 13100 | 15400 | 16500 |
| | 2.5 | 17400 | 19000 | 17500 | | 2.5 | 10800 | 16600 | 12500 |
| | 10 | 21200 | 21300 | 14200 | | 10 | 15300 | 15200 | 14900 |
| | 20 | 18700 | 13000 | 15700 | | 20 | 13200 | 13900 | 13800 |

Appendix C22. Lead (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 16 | 18 | 18 |
| | 2.5 | 17 | 18 | 18 |
| | 10 | 20 | 19 | 19 |
| | 20 | 17 | 14 | 20 |
| 6/13 | 0 | 14 | 15 | 14 |
| | 2.5 | 21 | 17 | 15 |
| | 10 | 15 | 16 | 16 |
| | 20 | 20 | 14 | 18 |
| 8/13 | 0 | 14 | 10 | 13 |
| | 2.5 | 12 | 8 | 18 |
| | 10 | 15 | 15 | 15 |
| | 20 | 14 | 16 | 19 |
| 10/21 | 0 | 21 | 22 | 17 |
| | 2.5 | 21 | 21 | 15 |
| | 10 | 21 | 15 | 14 |
| | 20 | 23 | 15 | 18 |
| **1987** | | | | |
| 4/28 | 0 | 20 | 13 | 18 |
| | 2.5 | 15 | 17 | 14 |
| | 10 | 18 | 15 | 22 |
| | 20 | 13 | 20 | 14 |
| 6/26 | 0 | 20 | 26 | 21 |
| | 2.5 | 18 | 21 | 17 |
| | 10 | 18 | 16 | 23 |
| | 20 | 25 | 14 | 19 |
| 8/21 | 0 | 14 | 16 | 16 |
| | 2.5 | 15 | 19 | 17 |
| | 10 | 16 | 16 | 17 |
| | 20 | 16 | 18 | 17 |
| 10/15 | 0 | 18 | 16 | 19 |
| | 2.5 | 18 | 15 | 18 |
| | 10 | 18 | 19 | 19 |
| | 20 | 19 | 17 | 18 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 19 | 16 | 13 |
| | 2.5 | 21 | 17 | 14 |
| | 10 | 16 | 17 | 17 |
| | 20 | 14 | 14 | 16 |
| 7/18 | 0 | 17 | 17 | 15 |
| | 2.5 | 18 | 19 | 20 |
| | 10 | 18 | 17 | 20 |
| | 20 | 13 | 12 | 13 |
| 8/29 | 0 | 18 | 21 | 22 |
| | 2.5 | 13 | 18 | 20 |
| | 10 | 16 | 22 | 19 |
| | 20 | 18 | 20 | 18 |
| 10/21 | 0 | 16 | 17 | 15 |
| | 2.5 | 19 | 17 | 15 |
| | 10 | 17 | 13 | 19 |
| | 20 | 16 | 13 | 15 |
| **1987** | | | | |
| 4/28 | 0 | 15 | 18 | 15 |
| | 2.5 | 16 | 17 | 17 |
| | 10 | 18 | 19 | 15 |
| | 20 | 12 | 16 | 17 |
| 7/17 | 0 | 21 | 19 | 17 |
| | 2.5 | 16 | 17 | 17 |
| | 10 | 16 | 19 | 20 |
| | 20 | 17 | 20 | 21 |
| 9/04 | 0 | 18 | 19 | 16 |
| | 2.5 | 16 | 21 | 15 |
| | 10 | 15 | 19 | 16 |
| | 20 | 17 | 17 | 20 |
| 10/15 | 0 | 11 | 21 | 16 |
| | 2.5 | 22 | 16 | 19 |
| | 10 | 15 | 15 | 15 |
| | 20 | 17 | 17 | 15 |

Appendix C23. Magnesium (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 1520 | 2000 | 3140 | 5/21 | 0 | 1820 | 2680 | 2200 |
| | 2.5 | 1820 | 1670 | 1750 | | 2.5 | 2320 | 2210 | 5440 |
| | 10 | 1750 | 1710 | 1750 | | 10 | 2690 | 2440 | 25710 |
| | 20 | 1590 | 1930 | 1950 | | 20 | 3030 | 2520 | 3610 |
| 6/13 | 0 | 1560 | 2110 | 5260 | 7/18 | 0 | 1770 | 2600 | 2150 |
| | 2.5 | 1730 | 1760 | 1770 | | 2.5 | 1750 | 2080 | 3120 |
| | 10 | 1450 | 1740 | 1770 | | 10 | 2590 | 2610 | 13900 |
| | 20 | 1840 | 1680 | 1940 | | 20 | 2840 | 2760 | 5900 |
| 8/13 | 0 | 1630 | 1920 | 2100 | 8/29 | 0 | 2050 | 2690 | 1970 |
| | 2.5 | 24240 | 1620 | 1570 | | 2.5 | 2130 | 2080 | 4300 |
| | 10 | 1620 | 1680 | 1600 | | 10 | 2710 | 2400 | 1450 |
| | 20 | 1600 | 1650 | 1970 | | 20 | 2650 | 2370 | 3750 |
| 10/21 | 0 | 1450 | 1990 | 2380 | 10/21 | 0 | 1910 | 2820 | 2230 |
| | 2.5 | 1670 | 1680 | 1640 | | 2.5 | 2090 | 1930 | 3990 |
| | 10 | 1610 | 1620 | 1720 | | 10 | 2270 | 2390 | 12760 |
| | 20 | 1760 | 1620 | 1810 | | 20 | 2820 | 2520 | 3340 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 2420 | 3000 | 2780 | 4/28 | 0 | 2050 | 2300 | 3210 |
| | 2.5 | 2600 | 2450 | 5590 | | 2.5 | 2200 | 1990 | 2000 |
| | 10 | 3140 | 2780 | 11000 | | 10 | 2020 | 2260 | 2010 |
| | 20 | 2990 | 3020 | 5390 | | 20 | 2000 | 1790 | 2210 |
| 6/26 | 0 | 2310 | 2870 | 3020 | 7/17 | 0 | 1920 | 1840 | 2640 |
| | 2.5 | 2030 | 2650 | 3330 | | 2.5 | 1610 | 1720 | 2110 |
| | 10 | 2800 | 2400 | 11330 | | 10 | 1660 | 1670 | 2370 |
| | 20 | 4110 | 2730 | 3540 | | 20 | 1570 | 1730 | 2340 |
| 8/21 | 0 | 2060 | 2430 | 1770 | 9/04 | 0 | 970 | 1610 | 2390 |
| | 2.5 | 1580 | 1970 | 2260 | | 2.5 | 1100 | 1090 | 1180 |
| | 10 | 2090 | 1810 | 10750 | | 10 | 1180 | 1240 | 1280 |
| | 20 | 1910 | 2240 | 3090 | | 20 | 1180 | 1350 | 1490 |
| 10/15 | 0 | 1430 | 2280 | 1890 | 10/15 | 0 | 1230 | 1650 | 2570 |
| | 2.5 | 1480 | 1620 | 2600 | | 2.5 | 1390 | 1390 | 1580 |
| | 10 | 2220 | 2090 | 15870 | | 10 | 1290 | 1440 | 1670 |
| | 20 | 2160 | 2050 | 3230 | | 20 | 1400 | 1450 | 1560 |

## Appendix C24. Manganese (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 500 | 720 | 590 | 5/21 | 0 | 600 | 600 | 590 |
| | 2.5 | 530 | 820 | 410 | | 2.5 | 700 | 660 | 600 |
| | 10 | 510 | 560 | 640 | | 10 | 680 | 580 | 470 |
| | 20 | 340 | 570 | 520 | | 20 | 710 | 590 | 610 |
| 6/13 | 0 | 480 | 790 | 520 | 7/18 | 0 | 600 | 620 | 600 |
| | 2.5 | 490 | 720 | 490 | | 2.5 | 670 | 570 | 660 |
| | 10 | 400 | 570 | 610 | | 10 | 670 | 630 | 560 |
| | 20 | 410 | 610 | 600 | | 20 | 660 | 580 | 590 |
| 8/13 | 0 | 560 | 830 | 670 | 8/29 | 0 | 630 | 650 | 650 |
| | 2.5 | 590 | 610 | 540 | | 2.5 | 610 | 590 | 650 |
| | 10 | 520 | 570 | 630 | | 10 | 670 | 620 | 520 |
| | 20 | 370 | 630 | 470 | | 20 | 640 | 620 | 590 |
| 10/21 | 0 | 510 | 670 | 480 | 10/21 | 0 | 650 | 650 | 620 |
| | 2.5 | 440 | 870 | 440 | | 2.5 | 620 | 600 | 620 |
| | 10 | 570 | 610 | 620 | | 10 | 610 | 640 | 550 |
| | 20 | 410 | 580 | 600 | | 20 | 720 | 610 | 580 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 590 | 620 | 610 | 4/28 | 0 | 480 | 710 | 410 |
| | 2.5 | 640 | 610 | 560 | | 2.5 | 480 | 1550 | 390 |
| | 10 | 700 | 610 | 500 | | 10 | 500 | 580 | 620 |
| | 20 | 640 | 630 | 550 | | 20 | 360 | 640 | 680 |
| 6/26 | 0 | 690 | 770 | 740 | 7/17 | 0 | 590 | 1160 | 550 |
| | 2.5 | 640 | 670 | 670 | | 2.5 | 490 | 920 | 460 |
| | 10 | 770 | 690 | 650 | | 10 | 440 | 530 | 840 |
| | 20 | 970 | 680 | 630 | | 20 | 390 | 690 | 720 |
| 8/21 | 0 | 780 | 840 | 870 | 9/04 | 0 | 880 | 930 | 620 |
| | 2.5 | 900 | 820 | 760 | | 2.5 | 660 | 1050 | 650 |
| | 10 | 960 | 880 | 790 | | 10 | 640 | 810 | 880 |
| | 20 | 970 | 880 | 800 | | 20 | 540 | 910 | 820 |
| 10/15 | 0 | 810 | 920 | 960 | 10/15 | 0 | 610 | 1060 | 890 |
| | 2.5 | 890 | 850 | 850 | | 2.5 | 720 | 900 | 480 |
| | 10 | 990 | 790 | 730 | | 10 | 620 | 680 | 860 |
| | 20 | 960 | 730 | 920 | | 20 | 560 | 680 | 730 |

## Appendix C25. Nickel (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 18 | 23 | 26 |
| | 2.5 | 25 | 22 | 24 |
| | 10 | 22 | 18 | 27 |
| | 20 | 19 | 23 | 23 |
| 6/13 | 0 | 19 | 27 | 26 |
| | 2.5 | 21 | 24 | 18 |
| | 10 | 17 | 19 | 27 |
| | 20 | 19 | 21 | 29 |
| 8/13 | 0 | 27 | 29 | 30 |
| | 2.5 | 31 | 25 | 22 |
| | 10 | 24 | 25 | 24 |
| | 20 | 24 | 26 | 25 |
| 10/21 | 0 | 24 | 28 | 30 |
| | 2.5 | 24 | 29 | 27 |
| | 10 | 31 | 21 | 26 |
| | 20 | 26 | 24 | 26 |
| **1987** | | | | |
| 4/28 | 0 | 19 | 23 | 23 |
| | 2.5 | 17 | 11 | 24 |
| | 10 | 15 | 14 | 15 |
| | 20 | 15 | 22 | 14 |
| 6/26 | 0 | 14 | 19 | 17 |
| | 2.5 | 12 | 17 | 15 |
| | 10 | 18 | 17 | 15 |
| | 20 | 27 | 16 | 15 |
| 8/21 | 0 | 10 | 14 | 12 |
| | 2.5 | 10 | 10 | 13 |
| | 10 | 14 | 12 | 13 |
| | 20 | 14 | 14 | 14 |
| 10/15 | 0 | 11 | 19 | 16 |
| | 2.5 | 11 | 13 | 13 |
| | 10 | 15 | 16 | 13 |
| | 20 | 14 | 14 | 13 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 26 | 32 | 32 |
| | 2.5 | 30 | 32 | 27 |
| | 10 | 33 | 33 | 27 |
| | 20 | 37 | 32 | 31 |
| 7/18 | 0 | 27 | 31 | 29 |
| | 2.5 | 24 | 23 | 30 |
| | 10 | 34 | 34 | 28 |
| | 20 | 34 | 30 | 26 |
| 8/29 | 0 | 28 | 38 | 32 |
| | 2.5 | 29 | 31 | 31 |
| | 10 | 36 | 36 | 24 |
| | 20 | 33 | 31 | 29 |
| 10/21 | 0 | 30 | 37 | 32 |
| | 2.5 | 29 | 30 | 30 |
| | 10 | 31 | 32 | 31 |
| | 20 | 34 | 33 | 25 |
| **1987** | | | | |
| 4/28 | 0 | 4 | 8 | 11 |
| | 2.5 | 12 | 15 | 7 |
| | 10 | 10 | 7 | 14 |
| | 20 | 1 | 8 | 11 |
| 7/17 | 0 | 13 | 15 | 11 |
| | 2.5 | 12 | 15 | 12 |
| | 10 | 11 | 12 | 16 |
| | 20 | 10 | 13 | 17 |
| 9/04 | 0 | 9 | 11 | 11 |
| | 2.5 | 11 | 12 | 8 |
| | 10 | 9 | 9 | 10 |
| | 20 | 9 | 8 | 10 |
| 10/15 | 0 | 7 | 13 | 13 |
| | 2.5 | 12 | 12 | 10 |
| | 10 | 14 | 10 | 12 |
| | 20 | 12 | 9 | 11 |

Appendix C26. Zinc (mg/kg) in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 40 | 40 | 33 | 5/21 | 0 | 35 | 43 | 38 |
| | 2.5 | 41 | 38 | 33 | | 2.5 | 41 | 42 | 43 |
| | 10 | 42 | 40 | 38 | | 10 | 43 | 39 | 36 |
| | 20 | 34 | 42 | 34 | | 20 | 47 | 42 | 45 |
| 6/13 | 0 | 36 | 46 | 36 | 7/18 | 0 | 44 | 44 | 34 |
| | 2.5 | 39 | 37 | 33 | | 2.5 | 38 | 36 | 37 |
| | 10 | 31 | 42 | 38 | | 10 | 45 | 44 | 39 |
| | 20 | 38 | 39 | 37 | | 20 | 44 | 41 | 34 |
| 8/13 | 0 | 43 | 44 | 41 | 8/29 | 0 | 38 | 44 | 39 |
| | 2.5 | 39 | 39 | 39 | | 2.5 | 37 | 38 | 37 |
| | 10 | 40 | 38 | 39 | | 10 | 46 | 40 | 36 |
| | 20 | 37 | 41 | 38 | | 20 | 42 | 41 | 34 |
| 10/21 | 0 | 41 | 42 | 37 | 10/21 | 0 | 42 | 45 | 41 |
| | 2.5 | 42 | 43 | 36 | | 2.5 | 40 | 37 | 40 |
| | 10 | 40 | 41 | 39 | | 10 | 45 | 44 | 36 |
| | 20 | 39 | 40 | 39 | | 20 | 46 | 45 | 37 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 41 | 44 | 41 | 4/28 | 0 | 43 | 44 | 38 |
| | 2.5 | 42 | 40 | 40 | | 2.5 | 45 | 43 | 33 |
| | 10 | 48 | 44 | 36 | | 10 | 42 | 44 | 39 |
| | 20 | 46 | 44 | 35 | | 20 | 37 | 39 | 43 |
| 6/26 | 0 | 54 | 61 | 56 | 7/17 | 0 | 56 | 50 | 46 |
| | 2.5 | 63 | 58 | 51 | | 2.5 | 54 | 53 | 49 |
| | 10 | 58 | 52 | 56 | | 10 | 52 | 59 | 57 |
| | 20 | 82 | 58 | 99 | | 20 | 67 | 60 | 60 |
| 8/21 | 0 | 36 | 44 | 37 | 9/04 | 0 | 43 | 47 | 40 |
| | 2.5 | 40 | 45 | 42 | | 2.5 | 48 | 47 | 33 |
| | 10 | 47 | 42 | 42 | | 10 | 46 | 47 | 42 |
| | 20 | 48 | 44 | 43 | | 20 | 39 | 52 | 46 |
| 10/15 | 0 | 44 | 49 | 46 | 10/15 | 0 | 48 | 45 | 39 |
| | 2.5 | 43 | 53 | 43 | | 2.5 | 44 | 43 | 41 |
| | 10 | 52 | 51 | 40 | | 10 | 44 | 53 | 48 |
| | 20 | 51 | 49 | 47 | | 20 | 43 | 46 | 45 |

Appendix C27. Percent Sand in Soil

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 5.4 | 2.8 | 2.8 | 5/21 | 0 | 3.1 | 0.4 | 1.3 |
| | 2.5 | 7.5 | 3.1 | 1.9 | | 2.5 | 3.3 | 1.0 | 1.4 |
| | 10 | 3.1 | 1.9 | 1.8 | | 10 | 2.2 | 0.6 | 1.9 |
| | 20 | 5.3 | 4.0 | 2.4 | | 20 | 2.0 | 1.1 | 1.3 |
| 6/13 | 0 | 2.8 | 2.5 | 2.9 | 7/18 | 0 | 2.9 | 1.6 | 2.0 |
| | 2.5 | 2.6 | 2.7 | 2.0 | | 2.5 | 2.4 | 2.3 | 1.5 |
| | 10 | 2.1 | 2.5 | 2.9 | | 10 | 0.9 | 1.6 | 2.3 |
| | 20 | 5.2 | 2.5 | 2.7 | | 20 | 1.6 | 1.6 | 1.4 |
| 8/13 | 0 | 0.2 | 0.6 | 3.0 | 8/29 | 0 | 1.2 | 1.2 | 1.0 |
| | 2.5 | 1.2 | 1.3 | 2.5 | | 2.5 | 2.9 | 1.1 | 1.5 |
| | 10 | 1.3 | 1.7 | 2.8 | | 10 | 2.9 | 1.3 | 1.7 |
| | 20 | 1.9 | 1.4 | 2.9 | | 20 | 2.2 | 0.9 | 1.8 |
| 10/21 | 0 | 2.7 | 1.4 | 1.8 | 10/21 | 0 | 1.4 | 0.2 | 0.9 |
| | 2.5 | 1.9 | 3.0 | 2.7 | | 2.5 | 1.8 | 1.1 | 1.2 |
| | 10 | 2.2 | 4.1 | 1.3 | | 10 | 1.4 | 1.0 | 2.2 |
| | 20 | 2.1 | 4.8 | 1.5 | | 20 | 3.1 | 0.5 | 2.0 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 1.6 | 1.0 | 1.7 | 4/28 | 0 | 0.8 | 4.1 | 1.2 |
| | 2.5 | 1.4 | 1.7 | 1.5 | | 2.5 | 1.2 | 4.7 | 1.9 |
| | 10 | 0.8 | 3.5 | 2.3 | | 10 | 1.6 | 4.1 | 1.8 |
| | 20 | 1.3 | 1.6 | 7.7 | | 20 | 1.2 | 3.6 | 1.2 |
| 6/26 | 0 | 17.2 | 11.6 | 9.1 | 7/17 | 0 | 18.1 | 3.8 | 5.7 |
| | 2.5 | 7.0 | 3.1 | 4.1 | | 2.5 | 4.9 | 4.2 | 6.8 |
| | 10 | 3.7 | 9.1 | 4.8 | | 10 | 5.8 | 4.5 | 8.2 |
| | 20 | 2.4 | 4.1 | 5.4 | | 20 | 4.5 | 3.2 | 6.6 |
| 8/21 | 0 | 3.4 | 3.5 | 12.3 | 9/04 | 0 | 3.3 | 5.3 | 6.3 |
| | 2.5 | 4.3 | 9.2 | 7.5 | | 2.5 | 3.2 | 1.5 | 13.9 |
| | 10 | 7.3 | 8.5 | 3.0 | | 10 | 3.0 | 7.0 | 7.4 |
| | 20 | 8.8 | 2.9 | 3.6 | | 20 | 3.8 | 4.5 | 7.1 |
| 10/15 | 0 | 2.4 | 2.1 | 7.2 | 10/15 | 0 | 2.6 | 9.3 | 4.0 |
| | 2.5 | 6.1 | 2.1 | 3.0 | | 2.5 | 8.0 | 7.0 | 3.0 |
| | 10 | 3.0 | 2.9 | 2.9 | | 10 | 5.5 | 5.8 | 3.5 |
| | 20 | 3.3 | 1.2 | 4.5 | | 20 | 7.7 | 6.2 | 2.7 |

## Appendix C28. Percent Silt in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 4/24 | 0 | 65.4 | 64.9 | 72.9 |
| | 2.5 | 69.2 | 63.7 | 72.9 |
| | 10 | 68.6 | 71.9 | 68.9 |
| | 20 | 68.2 | 65.9 | 73.9 |
| 6/13 | 0 | 70.1 | 69.7 | 72.4 |
| | 2.5 | 64.7 | 70.1 | 69.9 |
| | 10 | 71.5 | 71.4 | 68.7 |
| | 20 | 67.3 | 72.6 | 71.0 |
| 8/13 | 0 | 70.6 | 66.4 | 66.9 |
| | 2.5 | 67.8 | 68.3 | 66.2 |
| | 10 | 71.7 | 67.2 | 65.1 |
| | 20 | 63.5 | 71.7 | 65.7 |
| 10/21 | 0 | 63.0 | 66.4 | 69.0 |
| | 2.5 | 62.7 | 62.8 | 62.6 |
| | 10 | 64.0 | 65.5 | 67.2 |
| | 20 | 64.3 | 63.3 | 66.6 |
| **1987** | | | | |
| 4/28 | 0 | 66.8 | 70.5 | 72.1 |
| | 2.5 | 66.4 | 73.5 | 76.3 |
| | 10 | 66.7 | 91.1 | 81.0 |
| | 20 | 64.0 | 74.8 | 75.0 |
| 6/26 | 0 | 60.9 | 66.9 | 60.1 |
| | 2.5 | 74.8 | 72.0 | 72.4 |
| | 10 | 65.2 | 60.8 | 77.2 |
| | 20 | 66.5 | 75.1 | 66.8 |
| 8/21 | 0 | 76.9 | 68.6 | 65.9 |
| | 2.5 | 73.7 | 63.4 | 71.8 |
| | 10 | 65.6 | 62.1 | 79.5 |
| | 20 | 58.6 | 64.5 | 74.3 |
| 10/15 | 0 | 69.0 | 67.7 | 66.7 |
| | 2.5 | 68.8 | 67.7 | 73.3 |
| | 10 | 64.8 | 65.3 | 75.9 |
| | 20 | 62.9 | 68.4 | 72.1 |

| Date | Application Rate, t/a | Soybean Plots Rep 1 | Rep 2 | Rep 3 |
|---|---|---|---|---|
| **1986** | | | | |
| 5/21 | 0 | 65.8 | 64.1 | 64.6 |
| | 2.5 | 63.3 | 65.1 | 72.2 |
| | 10 | 60.9 | 66.5 | 75.2 |
| | 20 | 65.6 | 65.8 | 70.6 |
| 7/18 | 0 | 73.7 | 64.4 | 66.7 |
| | 2.5 | 69.4 | 69.4 | 71.8 |
| | 10 | 68.6 | 66.5 | 75.3 |
| | 20 | 62.9 | 65.5 | 70.4 |
| 8/29 | 0 | 65.5 | 65.3 | 65.6 |
| | 2.5 | 66.1 | 66.6 | 71.9 |
| | 10 | 59.9 | 65.6 | 74.3 |
| | 20 | 63.6 | 69.2 | 69.9 |
| 10/21 | 0 | 66.8 | 64.3 | 64.6 |
| | 2.5 | 63.7 | 65.8 | 70.0 |
| | 10 | 64.5 | 65.0 | 88.9 |
| | 20 | 56.6 | 68.5 | 68.7 |
| **1987** | | | | |
| 4/28 | 0 | 63.7 | 67.7 | 75.8 |
| | 2.5 | 65.1 | 71.0 | 69.9 |
| | 10 | 66.6 | 69.7 | 70.1 |
| | 20 | 68.0 | 74.0 | 75.7 |
| 7/17 | 0 | 61.8 | 86.0 | 80.8 |
| | 2.5 | 73.1 | 87.0 | 74.1 |
| | 10 | 73.3 | 83.4 | 73.3 |
| | 20 | 74.4 | 86.5 | 74.7 |
| 9/04 | 0 | 70.8 | 74.8 | 75.7 |
| | 2.5 | 64.3 | 72.4 | 59.6 |
| | 10 | 70.5 | 69.5 | 76.7 |
| | 20 | 68.5 | 73.9 | 70.8 |
| 10/15 | 0 | 71.5 | 62.8 | 76.0 |
| | 2.5 | 66.8 | 67.5 | 74.1 |
| | 10 | 71.2 | 72.5 | 71.8 |
| | 20 | 66.4 | 68.4 | 72.8 |

## Appendix C29. Percent Clay in Soils

| Date | Application Rate, t/a | Corn Plots Rep 1 | Corn Plots Rep 2 | Corn Plots Rep 3 | Date | Application Rate, t/a | Soybean Plots Rep 1 | Soybean Plots Rep 2 | Soybean Plots Rep 3 |
|---|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | **1986** | | | | |
| 4/24 | 0 | 29.2 | 32.3 | 24.3 | 5/21 | 0 | 31.1 | 35.5 | 34.1 |
| | 2.5 | 23.3 | 33.2 | 25.2 | | 2.5 | 33.4 | 33.9 | 26.4 |
| | 10 | 28.3 | 26.2 | 29.3 | | 10 | 36.9 | 32.9 | 22.9 |
| | 20 | 26.5 | 30.1 | 23.7 | | 20 | 32.4 | 33.1 | 28.1 |
| 6/13 | 0 | 27.1 | 27.8 | 24.7 | 7/18 | 0 | 23.4 | 34.0 | 31.3 |
| | 2.5 | 32.7 | 27.2 | 28.1 | | 2.5 | 28.2 | 28.3 | 26.7 |
| | 10 | 26.4 | 26.1 | 28.4 | | 10 | 30.5 | 31.9 | 22.4 |
| | 20 | 27.5 | 24.9 | 26.3 | | 20 | 35.5 | 32.9 | 28.2 |
| 8/13 | 0 | 29.2 | 33.0 | 30.1 | 8/29 | 0 | 33.3 | 33.5 | 33.4 |
| | 2.5 | 31.0 | 30.4 | 31.3 | | 2.5 | 31.0 | 32.3 | 26.6 |
| | 10 | 27.0 | 31.1 | 32.1 | | 10 | 37.2 | 33.1 | 24.0 |
| | 20 | 34.6 | 26.9 | 31.4 | | 20 | 34.2 | 29.9 | 28.3 |
| 10/21 | 0 | 34.3 | 32.2 | 29.2 | 10/21 | 0 | 31.8 | 35.5 | 34.5 |
| | 2.5 | 35.4 | 34.2 | 34.7 | | 2.5 | 34.5 | 33.1 | 28.8 |
| | 10 | 33.8 | 30.4 | 31.5 | | 10 | 34.1 | 34.0 | 8.9 |
| | 20 | 33.6 | 31.9 | 31.9 | | 20 | 40.3 | 31.0 | 29.3 |
| **1987** | | | | | **1987** | | | | |
| 4/28 | 0 | 31.6 | 28.5 | 26.2 | 4/28 | 0 | 35.5 | 28.2 | 23.0 |
| | 2.5 | 32.2 | 24.8 | 22.2 | | 2.5 | 33.7 | 24.3 | 28.2 |
| | 10 | 32.5 | 5.4 | 16.7 | | 10 | 31.8 | 26.2 | 28.1 |
| | 20 | 34.7 | 23.6 | 17.3 | | 20 | 30.8 | 22.4 | 23.1 |
| 6/26 | 0 | 21.9 | 21.5 | 30.8 | 7/17 | 0 | 20.2 | 10.2 | 13.5 |
| | 2.5 | 18.2 | 24.9 | 23.5 | | 2.5 | 22.0 | 8.8 | 19.1 |
| | 10 | 31.1 | 30.1 | 18.0 | | 10 | 20.9 | 12.1 | 18.5 |
| | 20 | 31.1 | 20.8 | 27.8 | | 20 | 21.1 | 10.3 | 18.7 |
| 8/21 | 0 | 19.7 | 27.9 | 21.8 | 9/04 | 0 | 25.9 | 19.9 | 18.0 |
| | 2.5 | 22.0 | 27.4 | 20.7 | | 2.5 | 32.5 | 26.1 | 26.5 |
| | 10 | 27.1 | 29.4 | 17.5 | | 10 | 26.5 | 23.5 | 15.9 |
| | 20 | 32.6 | 32.6 | 22.1 | | 20 | 27.7 | 21.6 | 22.1 |
| 10/15 | 0 | 28.6 | 30.2 | 26.1 | 10/15 | 0 | 25.9 | 27.9 | 20.0 |
| | 2.5 | 25.1 | 30.2 | 23.7 | | 2.5 | 25.2 | 25.5 | 22.9 |
| | 10 | 32.2 | 31.8 | 21.2 | | 10 | 23.3 | 21.7 | 24.7 |
| | 20 | 33.8 | 30.4 | 23.4 | | 20 | 25.9 | 25.4 | 24.5 |

Appendix D. Yields and Plant Parameters

| Sludge rate, t/a | CORN Yield, bu/a | CORN %grain moisture | CORN Test weight, lb/bu | CORN Population, plants/a | SOYBEANS Yield, bu/a | SOYBEANS %grain moisture | SOYBEANS Height, inches | SOYBEANS Population, plants/a |
|---|---|---|---|---|---|---|---|---|
| **1986** | | | | | | | | |
| **0** | 230.77 | 15.8 | 54.3 | 25,560 | 42.06 | 13.1 | 36.8 | 127,200 |
| | 212.03 | 16.0 | 53.3 | 24,390 | 32.77 | 13.0 | 38.5 | 137,650 |
| | 220.22 | 16.0 | 54.8 | 25,260 | 45.98 | 13.1 | 32.7 | 144,620 |
| 2.5 | 215.84 | 16.3 | 54.4 | 23,520 | 50.16 | 13.3 | 36.4 | 130,680 |
| | 201.94 | 16.4 | 54.6 | 24,100 | 32.62 | 13.5 | 38.5 | 137,650 |
| | 212.55 | 17.4 | 54.6 | 25,560 | 46.41 | 13.1 | 36.3 | 130,680 |
| 10 | 211.43 | 17.3 | 54.5 | 24,390 | 35.97 | 13.8 | 36.5 | 139,390 |
| | 198.60 | 15.9 | 55.7 | 22,070 | 38.72 | 13.0 | 36.3 | 130,680 |
| | 200.92 | 16.8 | 54.8 | 23,810 | 47.38 | 12.9 | 36.2 | 116,740 |
| 20 | 225.88 | 15.6 | 55.9 | 25,260 | 43.04 | 13.7 | 35.5 | 128,940 |
| | 223.76 | 16.2 | 56.3 | 25,560 | 39.66 | 13.3 | 37.1 | 115,000 |
| | 216.55 | 17.4 | 55.3 | 24,390 | 37.62 | 13.3 | 33.3 | 123,710 |
| **1987** | | | | | | | | |
| 0 | 210.44 | 18.1 | | 23,610 | 41.45 | 8.1 | 35.8 | 132,420 |
| | 121.06 | 18.1 | | 13,430 | 42.68 | 8.0 | 37.4 | 109,770 |
| | 157.92 | 19.1 | | 20,810 | 43.50 | 8.0 | 35.0 | 125,450 |
| 2.5 | 210.96 | 17.7 | | 24,200 | 41.66 | 8.0 | 35.2 | 121,100 |
| | 204.05 | 18.0 | | 21,540 | 41.64 | 8.0 | 37.6 | 108,900 |
| | 199.91 | 17.6 | | 21,840 | 35.83 | 8.0 | 32.3 | 130,680 |
| 10 | 101.75 | 17.6 | | 10,030 | 39.74 | 8.0 | 36.4 | 120,230 |
| | 129.98 | 17.3 | | 12,340 | 39.92 | 8.0 | 35.3 | 126,620 |
| | 180.22 | 17.2 | | 22,400 | 31.66 | 8.2 | 30.6 | 109,770 |
| 20 | 136.71 | 17.9 | | 11,660 | 38.74 | 8.7 | 36.3 | 103,670 |
| | 183.15 | 18.2 | | 20,660 | 45.96 | 8.2 | 34.8 | 124,580 |
| | 217.39 | 17.4 | | 21,100 | 40.21 | 8.1 | 37.9 | 124,580 |

Appendix E. Nutrients and Heavy Metals Concentrations in Grains

| | **Corn plots sludge applied, t/a** | | | | **Soybean plots sludge applied, t/a** | | | |
|---|---|---|---|---|---|---|---|---|
| **Constituent** | **0** | **2.5** | **10** | **20** | **0** | **2.5** | **10** | **20** |
| Aluminum | <10 | <10 | <10 | <10 | 12 | 11 | 14 | <10 |
| Al,mg/kg | <10 | <10 | <10 | <10 | <10 | 14 | <10 | <10 |
| | <10 | <10 | <10 | <10 | 14 | <10 | <10 | 11 |
| Cadmium | 0.1 | 0.1 | <.1 | <.1 | 0.3 | 0.2 | 0.3 | 0.2 |
| Cd, mg/kg | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| Calcium | 0.0070 | 0.0040 | 0.0040 | 0.0110 | 0.2080 | 0.1970 | 0.1970 | 0.2010 |
| Ca, % | 0.0090 | 0.0150 | 0.0080 | 0.0080 | 0.2080 | 0.2080 | 0.1980 | 0.1890 |
| | 0.0140 | 0.130 | 0.0100 | 0.0090 | 0.2030 | 0.2010 | 0.1990 | 0.2140 |
| Chromium | 0.2 | 0.2 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 |
| Cr, mg/kg | 0.2 | 0.2 | 0.2 | 0.0 | 0.4 | 0.3 | 0.3 | 0.3 |
| | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 |
| Copper | 1 | 2 | 1 | 1 | 13 | 12 | 12 | 12 |
| Cu, mg/kg | 1 | 1 | 1 | 2 | 12 | 12 | 13 | 12 |
| | 1 | 1 | 1 | 1 | 13 | 12 | 13 | 13 |
| Iron | 16 | 15 | 14 | 15 | 64 | 58 | 57 | 51 |
| Fe, mg/kg | 12 | 14 | 14 | 14 | 50 | 63 | 56 | 54 |
| | 12 | 11 | 12 | 13 | 66 | 65 | 54 | 67 |
| Lead | 0.4 | 0.4 | 0.1 | 0.4 | 1.5 | 1.5 | 1.8 | 1.5 |
| Pb, mg/kg | 0.4 | 0.3 | 0.3 | 0.4 | 1.5 | 1.7 | 1.4 | 1.4 |
| | 0.2 | 0.1 | 0.6 | 0.5 | 1.3 | 1.4 | 1.0 | 1.3 |
| Magnesium | 0.075 | 0.075 | 0.062 | 0.067 | 0.172 | 0.169 | 0.167 | 0.176 |
| Mg, % | 0.073 | 0.078 | 0.080 | 0.078 | 0.176 | 0.180 | 0.187 | 0.189 |
| | 0.066 | 0.069 | 0.071 | 0.073 | 0.170 | 0.194 | 0.184 | 0.184 |
| Manganese | 7 | 7 | 6 | 8 | 21 | 20 | 23 | 22 |
| Mn, mg/kg | 7 | 9 | 8 | 7 | 22 | 22 | 23 | 25 |
| | 6 | 6 | 8 | 8 | 23 | 24 | 24 | 22 |
| Nickel | 0.1 | 0.0 | 0.1 | 0.1 | 8.1 | 7.3 | 8.9 | 7.9 |
| Ni, mg/kg | 0.0 | 0.4 | 0.3 | 0.3 | 8.7 | 7.0 | 6.9 | 5.9 |
| | 0.4 | 0.4 | 0.0 | 0.4 | 8.8 | 2.4 | 2.6 | 3.0 |
| Nitrogen | 1.58 | 1.49 | 1.38 | 1.38 | 6.27 | 6.50 | 6.10 | 6.17 |
| N, % | 1.47 | 1.49 | 1.59 | 1.41 | 6.13 | 6.17 | 6.10 | 6.20 |
| | 1.34 | 1.37 | 1.49 | 1.49 | 6.48 | 6.21 | 6.01 | 6.22 |
| Phosphorus | 0.14 | 0.14 | 0.11 | 0.11 | 0.64 | 0.65 | 0.65 | 0.64 |
| P, % | 0.12 | 0.11 | 0.12 | 0.11 | 0.65 | 0.65 | 0.65 | 0.65 |
| | 0.10 | 0.09 | 0.12 | 0.11 | 0.62 | 0.64 | 0.61 | 0.61 |
| Potassium | 0.23 | 0.24 | 0.18 | 0.21 | 1.41 | 1.39 | 1.33 | 1.42 |
| K, % | 0.24 | 0.22 | 0.24 | 0.24 | 1.45 | 1.38 | 1.50 | 1.40 |
| | 0.23 | 0.22 | 0.19 | 1.20 | 1.40 | 1.53 | 1.45 | 1.41 |
| Zinc | <5 | 20 | 15 | 15 | 88 | 49 | 64 | 51 |
| Zn, mg/kg | 15 | 25 | 20 | 10 | 49 | 89 | 49 | 49 |
| | 44 | 20 | 15 | 20 | 54 | 55 | 54 | 52 |
| Crude protein | 9.86 | 9.30 | 8.63 | 8.64 | 39.20 | 40.60 | 38.14 | 38.59 |
| % | 9.16 | 9.33 | 9.94 | 8.84 | 38.14 | 38.54 | 38.12 | 38.77 |
| | 8.35 | 8.59 | 9.12 | 9.30 | 40.50 | 38.80 | 37.57 | 38.87 |
| Moisture, | 10.74 | 12.78 | 11.41 | 12.17 | 9.70 | 8.62 | 8.82 | 8.50 |
| % | 11.64 | 12.23 | 10.48 | 12.33 | 8.60 | 7.91 | 7.38 | 8.25 |
| | 10.47 | 11.64 | 11.25 | 11.81 | 7.55 | 9.00 | 7.44 | 8.00 |

Appendix F. Nutrients and Heavy Metals Concentration in Corn Whole Plants

| **Constituent** | **1986 sludge applied, t/a 0** | **2.5** | **10** | **20** | **1987 sludge applied, t/a 0** | **2.5** | **10** | **20** |
|---|---|---|---|---|---|---|---|---|
| Aluminum | 350 | 369 | 304 | 156 | 233 | 225 | 155 | 156 |
| Al,mg/kg | 71 | 75 | 85 | 179 | 64 | 190 | 185 | 416 |
| | 70 | 124 | 85 | 80 | 235 | 97 | 371 | 150 |
| Cadmium | 0.3 | 0.2 | 0.2 | 0.3 | 0.09 | 0.07 | 0.04 | 0.08 |
| Cd, mg/kg | 0.2 | 0.3 | 0.3 | 0.3 | 0.11 | 0.06 | 0.06 | 0.08 |
| | 0.2 | 0.2 | 0.2 | 0.2 | 0.09 | 0.01 | 0.05 | 0.06 |
| Calcium | 0.443 | 0.424 | 0.404 | 0.372 | 0.404 | 0.512 | 0.346 | 0.390 |
| Ca, % | 0.311 | 0.310 | 0.344 | 0.324 | 0.307 | 0.350 | 0.366 | 0.424 |
| | 0.362 | 0.393 | 0.406 | 0.380 | 0.412 | 0.280 | 0.571 | 0.364 |
| Chromium | 2.2 | 1.6 | 1.6 | 0.8 | 0.56 | 0.50 | 0.49 | 0.41 |
| Cr, mg/kg | 0.6 | 0.6 | 0.6 | 1.1 | 0.28 | 0.50 | 0.54 | 0.76 |
| | 0.5 | 0.7 | 0.6 | 0.7 | 0.63 | 0.29 | 0.77 | 0.36 |
| Copper | 5 | 4 | 4 | 6 | 3.7 | 4.2 | 5.6 | 4.6 |
| Cu, mg/kg | 5 | 5 | 6 | 5 | 5.4 | 3.2 | 3.9 | 4.8 |
| | 5 | 5 | 5 | 5 | 3.6 | 4.1 | 3.9 | 4.0 |
| Iron | 1390 | 890 | 1070 | 780 | 376 | 320 | 229 | 264 |
| Fe, mg/kg | 340 | 420 | 290 | 640 | 105 | 271 | 205 | 566 |
| | 290 | 460 | 290 | 340 | 321 | 141 | 460 | 223 |
| Lead | 17.0 | 6.9 | 6.4 | 4.0 | 1.2 | 1.7 | 1.3 | 1.7 |
| Pb, mg/kg | 2.7 | 2.5 | 2.7 | 4.0 | 0.8 | 1.2 | 1.4 | 2.0 |
| | 2.5 | 2.4 | 2.3 | 2.9 | 1.8 | 1.3 | 1.8 | 1.5 |
| Magnesium | 0.188 | 0.210 | 0.212 | 0.215 | 0.285 | 0.320 | 0.317 | 0.345 |
| Mg, % | 0.225 | 0.219 | 0.206 | 0.176 | 0.295 | 0.290 | 0.293 | 0.326 |
| | 0.288 | 0.248 | 0.259 | 0.250 | 0.274 | 0.250 | 0.383 | 0.284 |
| Manganese | 120 | 104 | 92 | 66 | 34 | 35 | 30 | 28 |
| Mn, mg/kg | 86 | 71 | 79 | 84 | 23 | 29 | 30 | 40 |
| | 39 | 63 | 62 | 37 | 48 | 11 | 32 | 20 |
| Nickel | 2.2 | 1.6 | 1.5 | 1.2 | 1.2 | 1.6 | 1.5 | 1.1 |
| Ni, mg/kg | 0.9 | 0.8 | 0.8 | 1.0 | 1.0 | 1.3 | 1.3 | 2.2 |
| | 0.6 | 1.0 | 0.8 | 0.8 | 1.6 | 0.8 | 2.1 | 1.3 |
| Nitrogen | 0.87 | 0.77 | 0.72 | 0.74 | | | | |
| N, % | 0.73 | 0.75 | 0.74 | 0.74 | | | | |
| | 0.78 | 0.73 | 0.82 | 0.70 | | | | |
| Phosphorus | 0.07 | 0.06 | 0.05 | 0.08 | | | | |
| P, % | 0.07 | 0.06 | 0.07 | 0.06 | | | | |
| | 0.06 | 0.05 | 0.05 | 0.05 | | | | |
| Potassium | 1.06 | 0.71 | 0.48 | 0.66 | 0.48 | 0.37 | 0.38 | 0.40 |
| K, % | 0.58 | 0.59 | 0.71 | 0.45 | 0.41 | 0.32 | 0.53 | 0.36 |
| | 0.41 | 0.67 | 0.42 | 0.48 | 0.41 | 0.31 | 0.28 | 0.32 |
| Zinc | 110 | 95 | 74 | 93 | 9.1 | 9.5 | 9.6 | 6.6 |
| Zn, mg/kg | 29 | 26 | 44 | 45 | 8.6 | 6.6 | 7.0 | 6.9 |
| | 79 | 57 | 30 | 25 | 6.1 | 7.3 | 7.5 | 5.3 |

Appendix G. Nutrients and Heavy Metals Concentration in Soybean Whole Plants

| | L986 sludge applied, t/a | | | | 1987 sludge applied, t/a | | | |
|---|---|---|---|---|---|---|---|---|
| **Constituent** | **0** | **2.5** | **10** | **20** | **0** | **2.5** | **10** | **20** |
| Aluminum | 135 | 172 | 364 | 195 | 31 | 25 | 26 | 30 |
| Al,mg/kg | 188 | 228 | 226 | 235 | 33 | 70 | 31 | 38 |
| | 230 | 137 | 137 | 138 | 31 | 39 | 112 | 77 |
| Cadmium | 0.4 | 0.4 | 0.4 | 0.4 | 0.52 | 0.48 | 0.30 | 0.26 |
| Cd, mg/kg | 0.4 | 0.4 | 0.3 | 0.3 | 0.51 | 0.33 | 0.51 | 0.72 |
| | 0.4 | 0.3 | 0.3 | 0.3 | 0.16 | 0.39 | 0.25 | 0.18 |
| Calcium | 0.994 | 0.929 | 0.867 | 0.805 | 1.073 | 1.060 | 1.053 | 0.981 |
| Cr, % | 0.914 | 0.979 | 0.912 | 0.817 | 0.945 | 1.071 | 1.023 | 1.206 |
| | 0.944 | 0.919 | 0.930 | 0.854 | 0.933 | 1.012 | 1.109 | 1.099 |
| Chromium | 0.7 | 0.8 | 1.0 | 0.8 | 0.19 | 0.18 | 0.14 | 0.23 |
| Cr, mg/kg | 0.7 | 0.8 | 0.9 | 0.8 | 0.12 | 0.14 | 0.13 | 0.12 |
| | 0.9 | 0.7 | 0.6 | 0.6 | 0.12 | 0.10 | 0.19 | 0.40 |
| Copper | 7 | 6 | 8 | 7 | 8.6 | 8.9 | 8.7 | 6.9 |
| Cu, mg/kg | 8 | 7 | 7 | 7 | 6.3 | 6.6 | 8.0 | 7.2 |
| | 7 | 5 | 5 | 6 | 7.0 | 8.5 | 7.3 | 6.3 |
| Iron | 400 | 420 | 540 | 390 | 72 | 39 | 59 | 62 |
| Fe, mg/kg | 490 | 410 | 390 | 490 | 70 | 112 | 64 | 72 |
| | 440 | 360 | 360 | 390 | 60 | 87 | 181 | 129 |
| Lead | 2.3 | 2.3 | 2.1 | 2.0 | 2.3 | 1.9 | 2.2 | 1.8 |
| Pb, mg/kg | 2.1 | 1.9 | 2.0 | 2.2 | 2.2 | 2.1 | 2.6 | 2.3 |
| | 2.0 | 2.1 | 2.0 | 1.8 | 1.7 | 2.0 | 2.1 | 1.9 |
| Magnesium | 0.304 | 0.298 | 0.239 | 0.237 | 0.537 | 0.602 | 0.581 | 0.468 |
| Mg, % | 0.328 | 0.285 | 0.307 | 0.256 | 0.546 | 0.550 | 0.540 | 0.600 |
| | 0.312 | 0.319 | 0.359 | 0.311 | 0.531 | 0.539 | 0.580 | 0.485 |
| Manganese | 47 | 42 | 57 | 36 | 20 | 16 | 15 | 13 |
| Mn, mg/kg | 44 | 50 | 48 | 47 | 18 | 22 | 14 | 13 |
| | 60 | 31 | 38 | 33 | 11 | 10 | 19 | 15 |
| Nickel | 1.5 | 1.7 | 2.6 | 1.4 | 2.5 | 1.9 | 2.0 | 1.5 |
| Ni, mg/kg | 1.7 | 1.9 | 2.2 | 1.8 | 2.1 | 2.2 | 2.1 | 2.5 |
| | 2.3 | 2.1 | 1.7 | 1.3 | 1.5 | 1.5 | 1.7 | 1.4 |
| Nitrogen | 1.11 | 1.12 | 1.56 | 1.38 | | | | |
| N, % | 1.43 | 1.64 | 1.27 | 1.40 | | | | |
| | 1.22 | 1.01 | 0.90 | 0.98 | | | | |
| Phosphorus | 0.09 | 0.10 | 0.18 | 0.13 | | | | |
| P, % | 0.17 | 0.14 | 0.13 | 0.14 | | | | |
| | 0.12 | 0.09 | 0.08 | 0.10 | | | | |
| Potassium | 0.34 | 0.36 | 0.30 | 0.35 | 1.05 | 0.67 | 0.75 | 0.79 |
| K, % | 0.38 | 0.30 | 0.40 | 0.34 | 0.58 | 0.76 | 0.87 | 0.86 |
| | 0.33 | 0.42 | 0.43 | 0.41 | 0.63 | 0.71 | 0.64 | 0.67 |
| Zinc | 36 | 27 | 23 | 54 | 11.2 | 9.7 | 11.1 | 7.1 |
| Zn, mg/kg | 30 | 31 | 15 | 30 | 7.7 | 9.5 | 10.2 | 9.8 |
| | 15 | 11 | 16 | 20 | 7.4 | 8.7 | 9.4 | 7.3 |

## Appendix H. Nutrients and Heavy Metals Concentration in Corn Leaves

| | **L986 sludge applied, t/a** | | | | **1987 sludge applied, t/a** | | | |
|---|---|---|---|---|---|---|---|---|
| **Constituent** | **0** | **2.5** | **10** | **20** | **0** | **2.5** | **10** | **20** |
| Aluminum | 31 | 32 | 37 | 29 | 24 | 24 | 20 | 26 |
| Al,mg/kg | 31 | 34 | 31 | 32 | 19 | 25 | 19 | 23 |
| | 30 | 30 | 36 | 26 | 20 | 14 | 31 | 17 |
| Cadmium | 0.3 | 0.3 | 0.3 | 0.4 | 0.10 | 0.10 | 0.17 | 0.19 |
| Cd, mg/kg | 0.4 | 0.4 | 0.3 | 0.4 | 0.13 | 0.15 | 0.13 | 0.24 |
| | 0.3 | 0.3 | 0.3 | 0.4 | 0.20 | 0.12 | 0.17 | 0.18 |
| Calcium | 0.579 | 0.653 | 0.679 | 0.645 | 0.694 | 0.751 | 0.773 | 0.869 |
| Ca, % | 0.607 | 0.547 | 0.592 | 0.595 | 0.720 | 0.822 | 0.733 | 0.944 |
| | 0.703 | 0.669 | 0.775 | 0.631 | 0.873 | 0.715 | 1.120 | 0.870 |
| Chromium | 0.5 | 0.5 | 0.5 | 0.5 | 0.24 | 0.25 | 0.17 | 0.21 |
| Cr, mg/kg | 0.5 | 0.5 | 0.4 | 0.4 | 0.24 | 0.15 | 0.21 | 0.13 |
| | 0.6 | 0.6 | 0.6 | 0.7 | 0.21 | 0.19 | 0.24 | 0.15 |
| Copper | 11 | 12 | 12 | 11 | 9.3 | 8.8 | 12:3 | 11.5 |
| Cu, mg/kg | 12 | 10 | 12 | 12 | 8.3 | 7.4 | 10.0 | 9.4 |
| | 11 | 11 | 12 | 11 | 12.1 | 8.6 | 9.5 | 10.7 |
| Iron | 90 | 190 | 310 | 290 | 97 | 114 | 94 | 103 |
| Fe, mg/kg | 290 | 240 | 240 | 190 | 115 | 97 | 89 | 107 |
| | 290 | 190 | 240 | 190 | 111 | 82 | 116 | 108 |
| Lead | 1.4 | 1.7 | 2.2 | 1.6 | 1.4 | 1.2 | 1.9 | 2.1 |
| Pb, mg/kg | 1.3 | 1.6 | 1.6 | 1.8 | 1.9 | 1.6 | 1.8 | 1.9 |
| | 2.0 | 2.0 | 2.1 | 2.6 | 1.7 | 1.8 | 2.4 | 2.2 |
| Magnesium | 0.232 | 0.281 | 0.289 | 0.328 | 0.352 | 0.383 | 0.508 | 0.547 |
| Mg, % | 0.320 | 0.258 | 0.251 | 0.273 | 0.355 | 0.424 | 0.384 | 0.386 |
| | 0.431 | 0.349 | 0.387 | 0.326 | 0.628 | 0.384 | 0.639 | 0.533 |
| Manganese | 137 | 128 | 149 | 115 | 72 | 49 | 61 | 59 |
| Mg, mg/kg | 137 | 132 | 121 | 107 | 60 | 45 | 59 | 68 |
| | 78 | 88 | 113 | 83 | 87 | 66 | 71 | 65 |
| Nickel | 1.0 | 1.2 | 1.4 | 1.3 | 1.4 | 1.5 | 1.8 | 1.8 |
| Ni, mg/kg | 1.3 | 1.1 | 0.9 | 1.0 | 1.8 | 1.5 | 1.5 | 1.8 |
| | 1.0 | 1.1 | 0.6 | 1.0 | 1.6 | 1.9 | 2.1 | 1.7 |
| Nitrogen | 2.76 | 2.55 | 2.57 | 2.76 | | | | |
| N, % | 2.84 | 2.13 | 2.86 | 2.72 | | | | |
| | 2.65 | 2.81 | 2.56 | 2.54 | | | | |
| Phosphorus | 0.37 | 0.35 | 0.33 | 0.34 | | | | |
| P, % | 0.36 | 0.30 | 0.38 | 0.33 | | | | |
| | 0.31 | 0.33 | 0.33 | 0.33 | | | | |
| Potassium | 1.84 | 1.76 | 1.89 | 1.75 | 1.26 | 1.22 | 0.88 | 1.00 |
| K, % | 1.70 | 1.87 | 1.86 | 1.83 | 1.26 | 1.18 | 1.20 | 1.01 |
| | 1.55 | 1.25 | 1.63 | 1.71 | 0.78 | 1.28 | 0.99 | 1.08 |
| Zinc | 30 | 40 | 44 | 29 | 19 | 28 | 22 | 23 |
| Zn, mg/kg | 35 | 30 | 39 | 40 | 27 | 13 | 18 | 14 |
| | 64 | 113 | 44 | 40 | 23 | 27 | 19 | 18 |

Appendix I. Nutrients and Heavy Metals Concentration in Soybean Leaves

| | L986 sludge applied, t/a | | | | 1987 sludge applied, t/a | | | |
|---|---|---|---|---|---|---|---|---|
| **Constituent** | **0** | **2.5** | **10** | **20** | **0** | **2.5** | **10** | **20** |
| Aluminum | 22 | 17 | 19 | 16 | 13 | 12 | 12 | 24 |
| Al,mg/kg | 16 | 14 | 23 | 20 | 15 | 26 | 22 | 14 |
| | 30 | 19 | 18 | 18 | 11 | 14 | 13 | 12 |
| Cadmium | 0.5 | 0.5 | 0.5 | 0.4 | 0.37 | 0.28 | 0.33 | 0.25 |
| Cd,mg/kg | 0.4 | 0.4 | 0.5 | 0.4 | 0.35 | 0.26 | 0.34 | 0.35 |
| | 0.5 | 0.4 | 0.4 | 0.4 | 0.13 | 0.33 | 0.24 | 0.20 |
| Calcium | 0.779 | 0.840 | 0.886 | 0.789 | 1.529 | 1.283 | 1.487 | 1.360 |
| Ca, % | 1.003 | 0.922 | 0.853 | 0.725 | 1.431 | 1.497 | 1.552 | 1.505 |
| | 0.934 | 0.988 | 0.899 | 0.853 | 1.271 | 1.596 | 1.876 | 1.291 |
| Chromium | 0.8 | 0.8 | 0.6 | 0.5 | 0.50 | 0.46 | 0.44 | 0.66 |
| Cr, mg/kg | 0.8 | 0.8 | 0.9 | 0.6 | 0.37 | 0.36 | 0.38 | 0.59 |
| | 0.7 | 0.7 | 0.8 | 0.6 | 0.29 | 0.30 | 0.27 | 0.36 |
| Copper | 10 | 10 | 10 | 10 | 11 | 10 | 10 | 11 |
| Cu, mg/kg | 10 | 10 | 11 | 9 | 13 | 12 | 13 | 11 |
| | 10 | 11 | 11 | 11 | 9 | 12 | 10 | 11 |
| Iron | 190 | 290 | 190 | 210 | 110 | 92 | 89 | 109 |
| Fe, mg/kg | 240 | 190 | 240 | 250 | 76 | 104 | 77 | 102 |
| | 140 | 340 | 240 | 290 | 70 | 85 | 83 | 89 |
| Lead | 1.8 | 2.0 | 2.2 | 2.9 | 2.6 | 2.0 | 2.3 | 3.7 |
| Pb, mg/kg | 2.2 | 2.4 | 2.6 | 2.3 | 2.7 | 3.3 | 2.8 | 2.5 |
| | 3.0 | 3.2 | 3.1 | 3.4 | 2.3 | 3.0 | 2.9 | 2.5 |
| Magnesium | 0.302 | 0.317 | 0.341 | 0.330 | 0.434 | 0.411 | 0.424 | 0.405 |
| Mg, % | 0.462 | 0.338 | 0.324 | 0.269 | 0.474 | 0.450 | 0.438 | 0.447 |
| | 0.345 | 0.339 | 0.331 | 0.346 | 0.414 | 0.550 | 0.562 | 0.389 |
| Manganese | | | | | 44 | 51 | 41 | 39 |
| Mn, mg/kg | | | | | 59 | 62 | 43 | 43 |
| | | | | | 30 | 38 | 43 | 44 |
| Nickel | 8.9 | 8.6 | 10.9 | 9.7 | 8.4 | 7.7 | 8.0 | 7.6 |
| Ni, mg/kg | 9.4 | 8.0 | 10.7 | 7.8 | 2.6 | 7.1 | 8.8 | 8.0 |
| | 10.5 | 3.2 | 4.7 | 4.6 | 2.9 | 5.2 | 4.0 | 4.8 |
| Nitrogen | | | | | | | | |
| N, % | | | | | | | | |
| Phosphorus | | | | | | | | |
| P, % | | | | | | | | |
| Potassium | 2.31 | 2.46 | 2.22 | 2.19 | 1.93 | 1.63 | 1.65 | 1.58 |
| K, % | 2.30 | 2.29 | 2.44 | 2.00 | 1.70 | 1.72 | 1.73 | 1.70 |
| | 2.32 | 2.41 | 2.26 | 2.31 | 1.19 | 1.34 | 1.31 | 1.63 |
| Zinc | 35 | 30 | 30 | 33 | 41 | 39 | 39 | 40 |
| Zn, mg/kg | 35 | 29 | 30 | 25 | 41 | 42 | 43 | 29 |
| | 134 | 25 | 50 | 30 | 39 | 38 | 38 | 40 |