TOXIC AND BENEFICIAL EFFECTS OF CHROME TANNERY SLUDGE ON CROPS

by

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ABSTRACT

The addition of tannery sludges to agricultural land may have benefits in terms of added nitrogen for crop growth. An experiment was designed using tannery sludge as nitrogen fertilizer to investigate the potential of it as an alternative to commercial fertilizer.

Soils containing 38% and 7% organic carbon (high and low organic matter soils, respectively) and having nitrogen contents of 1.3% and 0.2%, respectively, were amended with commercial nitrogen fertilizer or tannery sludge which contained 1.6% chromium. A portion of the tannery sludge was supplemented with additional chromium salt before addition to the soils. The resulting soils were than analyzed for total and available chromium and selected nutrient and trace element concentrations.

Corn, bush beans, and tall fescue were grown from seed in the soils and their tops were harvested, dried, and analyzed for chromium and selected element concentrations. Bush beans and corn were again grown from seed in the same soils 9 weeks after the first harvest and a third time 9 weeks after the second harvest. Tall fescue was cut 3 times and allowed to re-grow from the crown after the first and second cuttings. Nine weeks after the first harvest and at the end of the experiment, the same analyses that were conducted on the soils initially were conducted again.

The results of adding tannery sludge to soils were increased soil pH and total chromium concentration as well as increased concentrations of nitrogen, sulfur, phosphorus, magnesium, and sodium. Soluble chromium increased in soils with decreasing organic matter content and soil pH. The concentrations

of chromium in plant tops increased with increasing concentration of soluble chromium in the soil. At the first harvest, plant dry weight was increased with tannery sludge addition to the soil although to a smaller extent than with commercial nitrogen fertilizer. Plant dry weight at the second harvest was increased to a greater extent with tannery sludge addition than with commercial nitrogen fertilizer. The results of the analyses of the second harvest were similar to those observed at the first harvest. The dry weights of only corn and tall fescue increased, at the third harvest, to a greater extent with tannery sludge addition than with commercial nitrogen fertilizer.

Plants grew to less than 6% of the dry weight of the control or not at all in soils amended with tannery sludge that contained greater than 16% total chromium.

These results indicate that the growth of corn, tall fescue, and bush bean will increase as a result of tannery sludge addition to nitrogen deficient soil. Trivalent chromium, when present in tannery sludge at excessive concentration, will prevent or reduce plant growth.

no ¶ The dry weights of bush beans ~~at the third harvest,~~ did not differ with tannery sludge or commercial nitrogen fertilizer addition to the soils.

CONCLUSIONS

The dry weights of corn, tall fescue, and bush bean will increase as a result of tannery sludge application to soil that is nitrogen deficient. Although sludge application at the first planting does not stimulate plant growth to the same extent as commercial nitrogen fertilizer, significant stimulation of growth is observed. After sludge has remained in the soil 16 and 20 weeks, respectively, growth of corn and tall fescue is stimulated by tannery sludge to a greater extent than by commercial fertilizer. These results suggest that plant available nitrogen in soil amended with tannery sludge is renewed by mineralization of sludge nitrogen and/or altentuation of toxic materials in the sludge. Trivalent chromium salt causes lack of or reduced corn and bush bean growth when applied to soils with tannery sludge at concentrations which are 10-fold or more higher than those originally in the sludge. The presence of lime or a high organic matter content in the soil will alleviate some of the toxic effects of chromium in tannery sludge. The amount of growth of tall fescue in nitrogen deficient soil is not reduced by tannery sludge containing 10 times the amount of chromium initially present although growth is prevented or reduced when 100 times the initial amount of chromium is used. The growth of bush bean and corn is also prevented or reduced when sludge with 100 times the initial amount of chromium is added to soils. Additional experiments are required to study the problems of chromium toxicity and/or mineralization of sludge nitrogen.

RECOMMENDATIONS

Nitrogenous solid wastes from the leather tanning and finishing industry should be carefully characterized with respect to total elemental, toxics, and organic composition prior to disposal on agricultural land. If disposal on agricultural land should be recommended, the practice should not be continued on any one field for more than 10 years since accumulation of chromium may reduce crop yields to unacceptable levels. Although the results suggest that chromium is relatively immobile in soils, long term studies must be conducted in the field before the consequences of repeated tannery sludge applications are completely understood.

The maximum rate of tannery sludge application should be that which supplies adequate nitrogen for normal crop yield. Should the application rate be increased, the number of repeated applications should be proportionately decreased to prevent accumulation of potentially hazardous elements such as chromium, cadmium, and nickel in plants.

More greenhouse and laboratory work is needed to correlate uptake of certain heavy metals with their concentration in soils amended with tannery sludge and to determine sinks for chromium. Field work is needed to determine the quality and quantity of yields obtained from agricultural crops grown on tannery sludge amended soil as compared to yields with commercial nitrogen fertilizers.

INTRODUCTION

Tanneries generate over 45 thousand metric tons of waste materials a year as a result of trivalent chromium mediated leather tanning operations (Conrad et al., 1976). Wastewater treatment sludges account for 60% of the solid wastes from tanneries. Essentially all the potentially hazardous waste from the hair removal and tanning operations are present in these sludges which have been found to contain about 2% chromium, 6% nitrogen, 6% calcium, and a small combined quantity (0.06%) of zinc, lead, and copper. The elements potentially hazardous to living systems are chromium, zinc, lead and copper. About 60% of this solid waste is disposed of in landfills with the remainder disposed in trenches or lagoons. Disposal of chrome tannery sludges in landfills places thousands of pounds of chromium in a confined space. Lined landfills as opposed to open trenches or lagoons may be necessary to provide adequate health and environmental protection because of potentially hazardous waste constituents. An alternative to this method of disposal would be dispersion of sludges on large areas of crop land.

Wastewater sludges from the beamhouse and tanyard of a chrome tannery may have agricultural use in terms of added nitrogen and lime to soil to maintain crop growth. However, excessive amounts of trivalent chromium salts can reduce plant growth when applied to soil (Wallace et al., 1976; Mortvedt and Giordano, 1975; Kick and Braun, 1977). Consequently, addition of tannery sludges to soils may also result in reduced plant growth. Crop yield may thus be reduced if these industrial wastes are applied to agricultural soils indiscriminately.

A greenhouse investigation was conducted in which tannery sludge containing trivalent chromium was added to loess soil (low in organic matter), gley loam soil, and an acid sandy soil (Kick and Braun, 1977). The effect of the tannery sludge on growth, yield, and chromium content of spring rye, Serradella, green mustard, winter rye, winter wheat, spinach, and rye grass was studied. Sludge was applied such that the concentration of chromium ranged from 80 to 2884 mg per kg of soil. It was found that growth of all plant species tested decreased when the chromium concentration exceeded 500 mg per kg of soil when the pH was lower than 6.0. Addition of lime to loess and loam soils, to a pH higher than 6.0, raised the chromium toxicity threshold to 1000 mg per kg of soil. It was further observed by Braun that the chromium content in the grain of winter wheat and winter and spring rye were not influenced by any concentration of chromium in the soil. However, the chromium content of the green matter in mustard, rye grass, and spinach increased up to 23 mg per kg dry matter as the soil chromium increased. The solubility of chromium in ammonium acetate increased with increasing chromium concentration in the soils and was also proportional to uptake of the element by plants.

This investigation is designed to determine the toxic and/or beneficial effects on plant growth when tannery sludges that contain chromium are added to soils. The purpose is to help define an environmentally safe and beneficial means to utilize tannery sludges.

METHODS

Preparation of Soil Mixtures.

Tannery sludge was dried 24 hours in a forced draft oven at 50°C, pulverized in a hammer mill, and sieved to pass through a 2 mm screen. The sludge was characterized by analysis of lime equivalency, electroconductivity, chromium and selected element content prior to addition to soils (Table 1).

Two acid soils, one from the boundary area around Labish peat and having a high organic matter content and the other the A horizon of an Amity silty clay loam soil and low in organic matter, were collected from the Willamette Valley of Western Oregon and air dried. Each of the dry soils was sieved to pass through a 2 mm screen, homogenized in a cement mixer and analyzed for lime requirement, electroconductivity, cation exchange capacity, chromium, and selected element content prior to amendment with tannery sludge (Table 1). Each soil was then divided into two portions, one of which was limed by homogenizing with the calcium carbonate. The soils that resulted from these treatments are as follows (Tables 2-4): (1) acid soil high in organic matter, (2) acid soil low in organic matter, (3) neutral soil high in organic matter, and (4) neutral soil low in organic matter.

A portion of each acid soil was amended with tannery sludge equivalent to one-half, one, and two times the normal agricultural application rate of nitrogen for a given crop prior to planting (Tables 2-4). The amount of sludge added was based on the sum of the total soluble nitrogen (ammonium, nitrate, and nitrite) plus 18% of the total Kjeldahl nitrogen (Table 1). An equal portion of acid soil low in organic matter was amended with commercial fertilizer to nitrogen contents which are one-half, one, and two times the amounts required for normal crop growth prior to planting (Extension Service, 1978). No commercial fertilizer was added to the high organic matter soil because it contained nitrogen in quantities equivalent to or greater than that required for normal crop growth. Sludge quantities were added to the high organic matter soil in quantities equivalent to those added to the low organic matter soil.

Portions of tannery sludge were mixed with sugar reduced basic chromium sulfate (trivalent chromium), which is the compound used in chrome tanning. The tanning compound (16% chromium) was added to the tannery sludge, based on its chromium content, to concentrations which were 10 and 100 times the chromium concentrations measured initially in the sludge. These chromium supplemented sludges were applied to the acid soils in quantities equivalent to those which supply nitrogen in amounts required for normal growth of the plants (Table 2-4).

The two limed soils received the following additions: (1) commercial nitrogen fertilizer at twice normal application rate of nitrogen (Extension Service, 1978), (2) sludge at twice the normal agricultural application rate with respect to nitrogen, and (3) sludge at twice the normal agricultural application rate with respect to nitrogen plus chromium at 100 times the initial chromium concentration in the sludge (Tables 2-4). No commercial fertilizer was added to the limed high organic matter soil because it contained nitrogen in quantities equivalent to or greater than those required for normal crop growth. Sludge quantities added to the high organic matter soil were equivalent to those added to the low organic matter soil.

The soils with their various amendments were homogenized, assayed for numerous parameters (Tables 5-13), and placed in the greenhouse for plant culture.

Plant Culture.

Hybrid sweet corn (Zea Mays L. cv. Jubilee), bush bean (Phaseolus vulgaris L., cv. blue lake 53), and tall fescue (Festuca elatior L.) were grown in one-gallon capacity polyethylene containers which contained the various soil mixtures. The sides and bottom of each polyethylene container were covered with a layer of opaque plastic to exclude light and prevent algal growth. The plastic was covered with aluminum foil during the summer months to reflect the sunlight and reduce soil temperatures to ambient level in the greenhouse. The greenhouse was maintained at 24°C in the day and 18°C at night. Natural light was supplemented with sodium vapor lamps about 11,000 lux and a 16 hour photoperiod was maintained. The soil water content was maintained at 50% field capacity by daily addition of reverse osmosed (R/O) water equal to that lost by evapo-transpiration (Reuss et al., 1978). The quantity of water to be added was determined by weighing the soil and plant containers then adding water to a constant weight.

Seeds of corn, bush bean, and tall fescue were planted 6, 6, and 12 seeds per container, respectively. The number of seedlings which emerged from the soil were counted when it became evident that sprouting had ceased. This number was used to determine a percent emergence of seeds planted. Seedlings of corn and bush bean were then removed from each container until only two remained per container. No seedlings were removed from the fescue container.

Immediately after the second harvest, each soil mixture for corn and bush bean growth was homogenized in one pool per treatment, combining 4 replicates into one mixture. Two 200 g soil samples were taken from each homogenate and analyzed for pH, soil electroconductivity, and selected nutrient and trace element concentrations. The remaining soil from each treatment was again divided into 4 replicates per treatment and used for the third planting of corn and bush bean after a 9 week fallow period. The soil mixtures for tall fescue were sampled without disturbing the plants by removing a 100 g column of soil from each container. Soil from 2 of 4 replicates were combined into 200 g samples giving 2 samples per treatment which were analyzed for pH, soil electroconductivity, and selected nutrient and trace element concentrations.

Sample Collection.

The above ground organs of corn and bush bean were harvested 42 and 49 days after each planting, respectively. The soils in which corn and bush bean were planted remained fallow for 9 weeks after the first harvest and were then re-planted and harvested in the same manner. Percent emergence of seedlings was determined after each planting. The soils were again allowed to remain fallow 9 weeks after the second planting before being planted and harvested a third time. These procedures were repeated until there were three harvests of corn and bush bean. Tall fescue seeds were planted and seedling emergence was determined once at the beginning of the experiment. The fescue leaves were harvested on days 73, 146, and 292 by cutting them two inches above the soil surface. The leaves were allowed to grow again after the first and second harvests. There were four replicate containers of each soil treatment and plants from two were combined at each harvest. The plant material resulting from each harvest of corn, bush bean and tall fescue was dried 24 hours in a forced draft oven at 70°C, ground in a Wiley mill, and analyzed for nutrient and selected element content (Tables 17-25).

Assay of Nitrogenase.

Nitrogenase dependent reduction of acetylene to ethylene in the root nodules of bush beans was assyed by a modification of the method used to assay soil cores of corn and sorghum plants from the field (Barber et al., 1976). The lids were placed on the polyethylene containers with bush bean roots after plant tops had been harvested. A hole was cut in the center of each lid and then closed with a septum value. One-tenth volume of air was removed from the closed container by a hypodermic syringe and replaced by an equal volume of acetylene, giving 0.1 atm of the gas. Soils with the bush bean roots were incubated 3 hours with acetylene in air, after which a 1 ml gas sample was withdrawn from each container by a hypodermic syringe. Ethylene concentration in the sample was measured by gas chromatography.

Chemical Analyses.

Soil analyses were performed using the methods of soil analysis used in the soil testing laboratory at Oregon State University (Kauffman and Gardner, 1976). Some slight modifications to most of the methods were required for best performance. Total chromium analysis in soil was performed by reacting soil with nitric and hydrofluoric acids in a sealed plastic bottle. Chromium was then determined by atomic absorption spectrophotometry.

Plant tissue analysis for trace metals was performed by digesting the plant tissue with nitric and perchloric acids and determining trace metals on the inductively coupled plasma emission spectrometer. Calcium and potassium were measured with atomic absorption spectrophotometry on the same digest.

Total phosphorus and total nitrogen analyses were performed on the plant tissue and soil using a modified Kjeldahl procedure in which dry potassium sulfate, mercuric oxide and concentrated sulfuric acid are reacted with the plant tissue instead of a solution of the three (Am. Pub. Health Service, Am. Water Works Assoc., Water Pollut. Control Fed., 1976). Nitrogen and phosphorus were then determined colorimetrically on a Technicon autoanalyzer.

Justification and Summary of Statistical Analysis.

Valid use of the analysis of variance or the LSD (least significant difference) procedure requires that experimental errors be independently and normally distributed with a common variance. Randomization will usually ensure independence. Although violation of the normality assumption is rarely a serious problem, it is a procedure that allows treatment variances to depend upon treatment means. When treatment means fluctuate widely, the variances will also and a transformation of the data may be required (Steel and Torrie, 1960).

In these experiments, treatments means often varied greatly with treatment standard deviations increasing proportionally. Therefore, all data were transformed to their respective common logarithms for all statistical analysis (Steel and Torrie 1960, p. 157). Means, standard errors, and LSD's (least significant differences) were computed using the logarithmic data. The means given in Tables 15-25 and the graphs are geometric means, which are simply the antilogs of the means of the logarithmic data. The error bars in the graphs represent the antilog of the mean ± standard deviation of the logarithmic data. The antilog of the LSD for the log data yields a ratio to determine if two means differ significantly—the ratio of the larger to the smaller mean must exceed this value for statistical significance. The tables contain a percentage which is computed from the corresponding ratio and called the least significant percentage (LSP). The LSP gives the percentage increase of the larger mean over the smaller mean which is required for significance of difference. Each LSP value in the tables and graphs is percent of the smaller mean. The means in Tables 5-13 are arithmetical because a log transformation of these data was not required. Since the data in Table 14 were recorded as percent, log transformation was not performed and significance of difference between means was determined using the least significant difference (LSD) test.

RESULTS

Trace and Selected Elemental Composition.

Tannery sludge and soil. The tannery sludge contained most of the plant nutrient elements as well as several potentially hazardous trace elements such as chromium, zinc, and copper (Table 1). The concentration of chromium was 15.9 g/kg dry sludge, that of total nitrogen was 2.9%, and the concentration of soluble nitrogen (ammonium, nitrate, and nitrite) was 57 mg/kg dry sludge. The mean concentration of organic carbon in the high organic matter (HOM) soil was more than three times that in the low organic matter (LOM) soil before tannery sludge additions were made. More than twelve times as much soluble nitrogen was available for plant uptake in the HOM soil than in the LOM soil. The concentrations of soluble phosphorus, magnesium, and potassium in the HOM soil were 7, 2, and 3 times, respectively, those in LOM soil.

Soil mixtures. The total concentrations of the hazardous trace elements in the tannery sludge was decreased in the soil-sludge mixtures due to dispersion of sludge particles within the soil (Tables 2-5, 8 and 11). Before planting, the pH values of both the low organic matter (LOM) and the high organic matter (HOM) soils were increased when tannery sludge was added (Tables 5, 8, and 11). However, the pH increases did not occur to the same extent as those resulting from lime addition and the different pH values observed for each soil mixture reflected differences in lime requirements of the mixtures. Addition of both tannery sludge and lime decreased the electroconductivity and soluble phosphorus concentrations in the soil mixtures. The cation exchange capacities were greater in HOM soil than in LOM soil but did not increase consistently in either soil upon addition of tannery sludge. The inorganic carbon content of the soil mixtures increased with addition of tannery sludge although organic carbon did not appear to increase.

Total nitrogen did not appear to increase in LOM soil with addition of commercial nitrogen fertilizer although there were clearly increases in ammonia nitrogen (Tables 5, 8, and 11). Neither total nor ammonia nitrogen appeared to increase with increasing addition of tannery sludge despite a sludge nitrogen content of 2.8% (Table 1). Soluble calcium increased with increasing addition of tannery sludge to LOM soil but did not so increase in HOM soil and no increases were observed in either soil with addition of lime. Total sulfur, sulfate, total phosphorus, magnesium, and sodium concentrations increased in both LOM and HOM soil mixtures with sludge addition. Nitrate, nitrite, and soluble trace elements did not increase with addition of tannery sludge. The concentrations of soluble manganese and soluble phosphorus decreased in soil to which tannery sludge and/or lime had been added.

Twenty-three weeks after the first planting, pH values of the soil mixtures in which tall fescue and corn were grown had not changed from those observed before planting (tables 6, 9, and 12). Those soil mixtures containing tannery sludge and/or lime and planted with bush beans became slightly more acidic after 23 weeks and the lime requirements of these soils reflected the pH values. The inorganic carbon concentrations decreased in acid soils 23 weeks after tannery sludge had been added regardless of species grown, but the concentration of organic carbon did not change in any of the soils. Soluble calcium increased in high organic matter (HOM) soil 23 weeks after tannery sludge and/or lime had been added. An increase in soluble calcium was also observed in low organic matter (LOM) soil to which tannery sludge was added after liming. Soil electroconductivity increased 23 weeks after tannery sludge was added to soil regardless whether or not it had been limed.

Total nitrogen did not appear to change in the soil after 23 weeks of use. Ammonia content, however decreased 0.330.01 and 0.87-0.06 the initial values in soils amended with commercial fertilizer and tannery sludge, respectively when compared to ammonia concentrations in the same soils before planting (Tables 6, 9, and 12). Nitrate and nitrite increased 44% to 30-fold after 23 weeks in soil amended with commercial fertilizer and planted with bush bean or corn, but did not change in any soil in which tall fescue was growing. Nitrate and nitrite increases of 44% to 100-fold were observed in acid LOM soils amended with tannery sludge and planted with bush bean or corn but no changes were observed in sludge amended LOM soil planted with tall fescue. There were decreases in nitrate and nitrite concentration after 23 weeks in LOM and HOM soils which were limed and planted with tall fescue and in HOM soil mixtures planted with corn. The concentrations of total sulfur, total phosphorus, and soluble phosphate were essentially unchanged in the soils after 23 weeks. Sulfate increased in LOM soil planted with tall fescue, but was essentially unchanged in all other soils.

The concentration of soluble chromium in LOM soil amended with tannery sludge containing 100 times the initial concentration of chromium decreased to 0.25 the initial value after 23 weeks in soil planted with corn or bush bean while that in HOM soil amended with tannery sludge increased 47-fold when compared to that in soil before planting (Tables 6, 9, and 12). There was a 4-fold soluble chromium increase in LOM soil with 15.1 g Cr/kg (amended with tannery sludge containing 100 times the initial amount of chromium) and planted with tall fescue for 23 weeks. Soluble lead increased in acid LOM soil after 23 weeks and decreased with sludge addition to soil planted with fescue and corn. Lead decreased after 23 weeks in HOM soil planted with fescue and corn. Concentration of the element did not vary consistently with any of the amendments to soil planted with bush bean. Copper concentration decreased in HOM soil after 23 weeks when the pH was below 6.9, but it increased in LOM soil planted with fescue. Concentrations of zinc and manganese decreased with increasing amounts of sludge and increasing soil pH. Concentrations of cadmium, molybdenum, and boron had not changed after 23 weeks and were predominantly below levels which allowed precise measurement. The concentrations of soluble manganese in soils planted with bush bean and corn had not changed, however, those in soils planted with fescue increased when compared to those before planting. Soluble potassium decreased in HOM soil after 23 weeks and was lowest in soil planted with bush beans. There were increases in potassium concentration with increasing sludge addition to LOM soil planted with corn. Soluble potassium increased after 23 weeks in soils planted with tall fescue. Sodium increased in soils planted with corn or bush beans that did not contain tannery sludge. There was an an increase in sodium in HOM soil and a decrease in LOM soil planted with tall fescue. Soluble iron concentration increased in HOM soil planted with bush bean and corn and in all soils planted with tall fescue after 23 weeks. There was a decrease in iron concentration in LOM soil with increasing tannery sludge when the soil was planted with corn although the concentration increased in limed soil which did not contain sludge.

Several trends were observed in the final analyses of the soil mixtures. Soil electroconductivity, pH, soluble calcium, total sulfur, total chromium, sulfate, and soluble sodium increased with tannery sludge addition to low organic matter (LOM) and high organic matter (HOM) soils used to grow tall fescue (Table 7). Soil electroconductivity, total sulfur, total and soluble chromium, and sulfate were increased in the soil amended with tannery sludge supplemented with additional chromium. The pH values were higher in soil amended with tannery sludge and/or lime, but the soils become more acid when amended with sludge containing 100 times the initial concentration of chromium. The concentration of soluble chromium and sulfate in soils containing chromium supplemented sludge decreased when the soils were limed. The concentrations of soluble iron and manganese decreased in LOM soil as a result of tannery sludge or lime addition. However, the concentration of manganese increased in limed soil to which tannery sludge had also been added. Soluble boron increased in soil containing sludge supplmented with chromium salt although the increase was not proportional to the amount of chromium added. The concentration soluble chromium was lower in HOM than in LOM soil and lime addition further decreased the concentration in each soil. The concentration of ammonia was greater in soils containing sludge with 100 times the initial concentration of chromium than in any of the other soils. HOM soil with 14.8 g chromium per kg soil contained more ammonia than any of the other soils.

Soluble chromium, total sulfur, total chromium, sulfate, nitrate and nitrite, and soluble sodium concentrations were greater in the final analysis of soils for bush bean growth when tannery sludge and chromium was added and they increased with sludge addition (Table 10). Soil pH also increased with supplemental chromium salt addition. Addition of lime decreased the lime requirement (increased pH units) but chromium supplemented LOM soil remained very acid. Soil electroconductivity was greater in chromium supplemented soils and increased in HOM soil with increasing tannery sludge addition. Total sulfur, total chromium, soluble chromium, sulfate, and soluble sodium concentrations were greater in soil supplemented with addition chromium salt. The concentrations of manganese and boron were greater in soils containing sludge supplemented with more than 9 grams of chromium per kg (100 times the initial concentration in the sludge) than in the other soils. HOM soil supplemented 9.2 grams chromium per kg soil contained more ammonia than any soil. The concentration of soluble manganese decreased when tannery sludge or lime was added to soils. The concentration of soluble chromium was higher in LOM soil with chromium supplemented sludge than in HOM soil with the same total chromium concentration and soluble chromium also decreased when the soils were limed.

Final analysis of soil mixtures for corn growth revealed that both soil pH and electroconductivity increased with tannery sludge addition to soils (Table 13). Soil pH decreased while electroconductivity increased further when the sludge was supplemented with chromium salt before addition to soils. Soluble calcium, total chromium, and soluble sodium concentrations increased with tannery sludge addition to soils. Total sulfur, total and soluble chromium, sulfate, and soluble sodium concentrations increased further when the tannery sludge was supplemented with chromium salt. The concentration of ammonia was greater in HOM soil containing 16.1 g chromium per kg (sludge had 100 times initial concentration of chromium) than in any other soil mixture. The concentration of nitrates and nitrites increased in LOM soils amended with commercial nitrogen fertilizer, tannery sludge or lime. The concentration of soluble phosphorus decreased in HOM soil amended with tannery sludge or lime. The concentration of iron in LOM soil decreased with tannery sludge or lime addition. The concentration of manganese decreased with tannery sludge or lime addition to soils although an increase was observed which the soil were supplemented with addition chromium salt. There was also more boron in the chromium supplemented soils.

The concentration of soluble potassium decreased in all soils for fescue growth, but that of zinc increased in acid HOM containing tannery sludge and in limed HOM control soils throughout the experiment (Tables 5-7). The soil electroconductivity increased throughout the experiment in all soils for corn growth except limed LOM soil. Soluble lead concentration increased in the limed control and in acid HOM soils for corn growth that contained tannery sludge. Soluble chromium decreased in acid and limed soils that contained 16 g chromium per kg dry soil (tannery sludge supplemented with 100 times the initial concentration of chromium) and planted with corn).

Effect on Seedling Emergence.

Seedlings failed to emerge at the first planting when corn, tall fescue, or bush bean seeds were planted in acid and limed LOM (low organic matter) soil to which sludge containing chromium salt at 100 times the initial concentration was added (Table 14). Percent seedling emergence was decreased to 30% or less at the first planting in all species when seeds were planted in HOM (high organic matter) soil to which chromium was added at the preceeding concentration. Percent emergence was greater than 80% in all species when LOM or HOM soil were amended with quantities of commercial fertilizer or sludge that gave half the nitrogen required for normal crop growth and when HOM soil was limed and further amended with the quantity of sludge that is twice normal agricultural application rate with respect to nitrogen. Addition of either tannery sludge or commercial nitrogen fertilizer to acid LOM soil resulted in increased rates of fescue and bush bean seedling emergence at the first planting.

Only three soil mixtures caused a significant decrease in bush bean seedling emergence at the second planting; these were acid and limed LOM and acid HOM soil, each of which contained tannery sludge with 100 times the amount of chromium initially present in the sludge (Table 14). The acid and limed LOM and acid HOM soils with 100 times the initial concentration of chromium in the sludge allowed 0, 0, and 77%, respectively, of the seeds planted to emerge as seedlings. There were no statistically significant decreases in bush bean seedling emergence in limed HOM soil to which the same amount of chromium had been added. Similar effects were observed in corn seedlings emergence, however, a significant decrease was also observed when the HOM soil was limed before adding sludge containing 100 times the initial concentration of chromium.

At the third planting, bush bean seedlings did not emerge from LOM soil containing tannery sludge with 100 times the initial concentration of chromium regardless whether or not the soil had been limed (Table 14). Emergence was significantly reduced in HOM soil containing the same amount of chromium. Bush bean emergence was not decreased significantly in any of the other soil mixtures. Corn seedlings did not emerge at the third planting from LOM soil containing tannery sludge with 100 times the initial concentration of chromium regardless whether or not the soil mixture was limed. Corn seedling emergence was significantly reduced in HOM soil containing tannery sludge with 100 times the initial concentration of chromium. Corn emergence at the third planting was not decreased significantly in any of the other soil mixtures.

Effects on Tall Fescue.

Growth. The dry weight of tall fescue continued to increase after emergence from soil amended with either tannery sludge or commercial nitrogen fertilizer, but the amount of growth sustained by the sludge was less that sustained by commercial fertilizer in the LOM (low organic matter) soil (Figs. 1-4). Fescue grown in the LOM and HOM (high organic matter) soils amended with tannery sludge contained more dry matter than those plants grown on the same soils without amendment. The dry weight of fescue was not decreased in LOM soil amended with sludge containing 10 times the initial concentration of chromium (Table 17). Tall fescue did not survive when 100 times the initial concentration of chromium was present in sludge used to amend LOM and HOM soil. When the HOM soil was limed before addition of tannery sludge containing 100 times the initial concentration of chromium, plant dry weight was reduced 94% below that on both acid and limed HOM soils which were not amended.

The dry weights of tall fescue increased with increasing tannery sludge addition to LOM soil at the second and third harvests and were greater in those plants were grown on sludge amended soil than on that amended with commercial nitrogen fertilizer (Figs. 6-8). The dry weights of plants grown on HOM soil also increased with increasing tannery sludge addition. The dry weights of tall fescue grown on LOM soil amended with tannery sludge containing 10 times the initial concentration of chromium were greater at the second and third harvests than those of comparable plants grown on non-amended LOM soil (Table 15). Plants grown on acid HOM soil amended with tannery sludge containing 10 times the initial concentration of chromium did not differ from comparable control plants grown on non-amended HOM soil at the second an third harvests. At the second harvest, plants grown on limed HOM soil that was amended with tannery sludge containing 100 times the initial concentration of chromium weighed more than those grown on acid HOM soil without addition but less than those on HOM soil which had only been limed. At the third harvest, the dry weights of plants grown on limed HOM soil with no other additions and those grown on the same soil amended with sludge containing 100 times the initial concentration of chromium did not differ. However, the latter group of plants weighed less than those plants grown in non-amended acid HOM soil.

Elemental composition. The first harvest concentrations of nitrogen, phosphorus, and sulfur in tall fescue increased with increasing commercial nitrogen fertilizer addition to LOM (low organic matter) soil (Table 17). Concentration of nitrogen increased 20% above the LOM control and 43% above the HOM control in plants grown at the largest tannery sludge additions to LOM and HOM (high organic matter) soils, respectively. Phosphorus, however, decreased in plants from both soils with tannery sludge and lime addition, but changes in sulfur concentration did not correlate with addition of tannery sludge. Calcium concentration increased with sludge and lime addition to HOM soil but differences in concentrations of calcium in plants grown on LOM soil were not correlated with additions to the soil. The concentration of magnesium increased in tall fescue grown in LOM and HOM soils with increasing commercial fertilizer and tannery sludge additions. Concentration of chromium increased with increasing sludge addition to acid HOM soil and limed LOM and HOM soils. Ten and 100-fold additions of chromium to sludge before addition to soils did not result in proportionately greater chromium concentrations in tall fescue. The concentrations of soluble iron and manganese decreased in plants as the organic matter content increased in the soil mixtures.

At the second cutting of tall fescue, the average concentration of nitrogen for all treatments was about 50% lower than that in the first harvest and varied with concentrations in soil after 23 weeks from beginning of experiment rather than with additions made at the beginning (Table 18). The concentrations of phosphorus, sulfur, magnesium, copper and zinc decreased in tall fescue grown in low organic matter (LOM) soil that had commercial nitrogen fertilizer added. The concentrations of phosphorus, sulfur, calcium, and magnesium decreased in plants from LOM soil that had tannery sludge added. Nitrogen and manganese concentrations decreased in plants from high organic matter (HOM) soil to which sludge was added and manganese concentration decreased with increasing pH and organic matter content of all soils. The concentration of chromium in tall fescue generally varied with the soluble chromium in the soil although there were increases in plants grown in limed soil which could not be accounted for in terms of increases in soluble chromium.

At the third cutting of tall fescue, the concentrations of nitrogen and potassium in plants were generally decreased below those at the second cutting while the concentrations of phosphorus, chromium and iron were increased (Tables 18 and 19). The concentrations of copper and lead were increased in plants growing on soil amended with tannery sludge and lime at the third cutting above those growing in the same soil mixtures at the second cutting. The concentration of nickel was increased in plants from all soil mixtures except the LOM (low organic matter) and HOM (high organic matter) control soils which did not receive commercial nitrogen fertilizer, tannery sludge, or lime additions.

The concentrations of nitrogen and phosphorus in the third cut of tall fescue grown on LOM soil amended with 320 pounds of commercial nitrogen per acre were significantly below those of plants from the control LOM soil (Table 19). The concentration of nitrogen was greater in tall fescue harvested from LOM soil having 1.37 g chromium per kg dry soil (amended with tannery sludge containing 10 times the initial concentration of chromium) than in plants from control LOM soil. The concentrations of phosphorus and boron initially increased in plants from LOM soil which received tannery sludge but decreased with larger sludge additions. The concentration of phosphorus decreased in plants from high organic matter (HOM) soils with sludge addition and when chromium salt was added to the sludge. Sulfur in plants from LOM and HOM soils amended with commercial fertilizer and tannery sludge, respectively, increased when the soils were amended but decreased as further addition of each amendment was made. Sulfur concentration was statistically greater in plants from limed HOM soil with 14.6 g chromium per kg dry soil (containing sludge with 100 times the initial chromium concentration) than in plants from the limed control HOM soil. The concentrations of calcium, potassium and copper increased in plants from LOM soil with addition of commercial nitrogen fertilizer. The concentration of calcium was significantly greater in plants from limed HOM and LOM soil containing sludge than in those from the limed control soils, but it decreased when chromium salt was added.

The concentration of cadmium increased in at the third cut of tall fescue from HOM soil that received tannery sludge with additional chromium salt. The concentration chromium increased in plants as a result adding chromium salt to sludge used to amend LOM and HOM soils. The concentrations of chromium in plants grown on soil amended with tannery sludge were greater than those from corresponding control soils, but the concentrations in plants from LOM soil containing commercial fertilizer were not significantly different from those in plants from LOM soil containing the corresponding quantities of tannery sludge based on nitrogen content. Copper concentrations increased in tall fescue when grown in LOM soil containing commercial nitrogen fertilizer. The concentration of nickel increased in plants grown on LOM and HOM soil mixed with tannery sludge as the amount of added sludge increased. The concentration of manganese decreased in plants growth on HOM soil mixed with tannery as the amount of added sludge increased; the concentration also decreased in plants from limed control soils.

Effects on Bush Beans.

Growth. After the first planting, dry weights of bush bean plants increased with addition of tannery sludge to soils through the quantity equivalent to the amount of nitrogen required for normal crop growth prior to planting (Figs. 9-12). No further growth increase in dry weight occurred beyond this addition. Bush bean dry weights did not change significantly as a result of sludge addition to HOM (high organic matter) soils when compared to control HOM soil without addition of sludge or commercial fertilizer. There was neither increase nor decrease in growth with further addition of sludge to HOM soil. Bush bean clearly accumulated more dry matter in acid soil than in limed soil regardless or other soil amendments(Table 15). At the first harvest, the chromium additions significantly decreased the dry weights of all bush bean plants so treated and none of them survived when sludge containing 10 and 100 times the initial amount of the element was added to LOM soil. Although bush bean grew in acid and limed HOM soil amended with tannery sludge containing 100 times the initial concentration of chromium, the dry weights were decreased 95% and 90% respectively (Fig. 13).

The dry weights of bush beans grown on HOM soil were greater at the second harvest than that on (LOM) low organic matter soil when no fertilizer or sludge additions were made (Fig. 14). However, there were no significant dry weight differences between treatments in soils where additions were made, regardless of whether tannery sludge or commercial nitrogen fertilizer was added. A decrease in growth was observed in HOM soil containing tannery sludge. Comparison of the data in Figure 14 with that in Figure 9 shows the growth stimulation obtained with tannery sludge persisted longer when compared to that with commercial nitrogen fertilizer (Figure 15). Chromium additions decreased the dry weight of bush bean at the second harvest although to a smaller extent than was observed in the first one (Table 15). The dry weights of bean plants grown in LOM soil amended with tannery sludge containing 10 times the initial concentration of chromium were reduced 40% below those in control LOM soil. No plants survived in the same soil amended with sludge containing 100 times the initial concentration of chromium. The dry weights of bush beans were not reduced below the control at the second harvest when plants were grown in HOM soil amended with sludge containing 10 times the initial concentration of chromium. When the chromium concentration was raised to 100 times the initial value in the sludge, dry weights were reduced 87% and 80% in acid and limed HOM soil, respectively.

At the third harvest, the dry weights of bush beans grown in LOM soil containing the various amounts of commercial nitrogen fertilizer did not differ from those in control LOM soil containing no fertilizer or tannery sludge additions (Fig. 16). Bush beans grown on LOM soil containing tannery sludge equivalent to the quantities of nitrogen in the commercial nitrogen fertilizer weighed the same as those plants grown on control LOM soil. The dry weights of bush beans grown on HOM soil responded positively to sludge additions equivalent to half and one times the quantity of nitrogen required for normal plant growth. However, the weights were all significantly lower than those of plants grown on control HOM soil containing no fertilizer or sludge additions. Bush beans did not grow on acid or limed LOM soil amended with tannery sludge containing 100 times the initial amount of chromium. The dry weights did not differ among plants grown on LOM, HOM, and limed HOM soil amended with tannery sludge containing 10, 10 and 100, and 100 times the initial concentration of chromium, respectively (Table 15).

Nitrogenase activity. There was decreasing nitrogenase activity in bush bean nodules with increasing tannery sludge and commercial nitrogen fertilizer additions to soil (Figures 17-18). Nitrogenase activity was minimal in LOM soil amended with sludge in an amount equivalent to twice the nitrogen required for normal bush bean growth. Nitrogenase activity did not decline in HOM soil amended with sludge at the first harvest (Fig. 17). Addition of chromium to tannery sludge in an amount equal to 10 times that initially in the sludge and adding the mixture to HOM soil (0.84 g Cr/kg soil) did not decrease nitrogenase activity at the first harvest, but there were decreases at the subsequent harvests. Activity was decreased at all three harvests and in every soil combination where sludge containing 100 times the initial amount of chromium was applied. Nitrogenase activity was also decreased in each soil to which lime was applied with and without commercial fertilizer or sludge addition. The effects of tannery sludge and commercial nitrogen fertilizer addition to soils were relatively similar in each of the three harvests although nitrogenase activity declined with each subsequent harvest.

Elemental composition. The concentrations of phosphorus and boron were decreased in plants from limed soil at the first harvest of bush beans (Table 20). The concentration of manganese in bush beans decreased with increasing tannery sludge addition to HOM soil (R = -0.90). The concentration of the element also decreased 72% and 88% below the controls in bush beans grown in limed LOM and HOM soils, respectively, which had not received tannery sludge. The concentration of manganese was decreased 85% below the HOM control in limed HOM soil which was amended with sludge. The concentration of magnesium increased with addition of commercial nitrogen fertilizer to LOM soil. The concentrations of chromium in bush beans increased as the quantity of sludge added to HOM soil increased (R = 0.98). However, the chromium concentration in those plants grown on HOM soil amended with sludge containing a 10-fold addition of the element (0.84 g Cr/kg soil) did not differ statistically from that in plants grown in the same soil amended with tannery sludge without added chromium. The concentration of chromium in bush beans grown on HOM soil amended with tannery sludge containing a 100-fold addition of the element was 4.6 times that in HOM soil containing sludge with the 10-fold addition when the former soil was not limed and 6.0 times that when it was limed.

At the second harvest, the concentrations of the macronutrient elements, except calcium, in bush beans were not different from those in the first harvest (Table 21). The concentrations of calcium, and the micronutrient element manganese were greater at the second harvest and plants absorbed more calcium from limed soil than from acid soil. The concentrations of nitrogen in bush beans at the second harvest grown on low organic matter (LOM) soil amended with tannery sludge increased as the quantity of sludge increased. Those nitrogen concentrations in plants grown on soil amended with commercial nitrogen fertilizer increased as the fertilizer increased but were lower than the concentrations in plants from sludge amended LOM soil. The magnesium concentrations in plants grown on LOM soil amended with commercial nitrogen fertilizer and tannery sludge increased as the quantity of each amendment increased but the increases were greater with tannery sludge. The concentration of zinc increased in bush bean grown on high organic matter (HOM) soil as tannery sludge increased (R = 0.98).

The concentrations of chromium in the second harvest of bush beans from LOM soil amended with tannery sludge containing 10 times the initial amount of chromium were twice those in plants from the same soil amended with sludge containing no added chromium. Plants from acid and limed HOM soil amended with sludge containing 100 times the inital chromium concentration absorbed 2.8 and 6.3 times, respectively, as much of the element in their tops as plants from the same soils amended with sludge lacking the added chromium.

The concentrations of boron, cadmium, copper, lead, manganese, nickel, and zinc in plants grown on soil containing the higher concentration of chromium were greater than in those plants from all other soil mixtures.

The concentrations of nitrogen, phosphorus, cadmium, chromium, copper, and nickel in bush beans were higher at the third harvest than at the second (Tables 21 and 22). The concentration of zinc was higher in plants grown on the unlimed soils at third harvest than it was in plants from the same soils at the second harvest.

Analysis of the third harvest of bush beans also revealed that the concentration of phosphorus was lower in plants grown on limed soils than of the corresponding acid soils (Table 22). The concentration of sulfur was greater in bush beans from soils containing chromium supplemented tannery sludge than in plants from soil containing sludge without the additional chromium. The concentration of cadmium, chromium and nickel were greater in plants from soils amended with sludge containing added chromium than in those from any other soils; the concentration of copper was greater only in plants from HOM soil with 9.1 or 9.2 g Cr per kg soil (soil containing sludge with 100 times the initial concentration of chromium). The concentration of manganese increased with commercial nitrogen fertilizer addition to soils, but decreased with tannery sludge and lime additions. Then concentration of manganese was higher in the plants from LOM soil which received tannery sludge supplemented with chromium salt than in any of the other soils. The concentration of nickel decreased in plants grown in LOM soil with commercial fertilizer addition to the soil. The concentration of zinc decreased in bush beans grown in limed soils when compared to the corresponding acid soils.

Effects on Corn.

Growth. The dry weights of corn increased at the first harvest when commercial nitrogen fertilizer or tannery sludge were applied to low organic matter (LOM) soil equivalent to half the quantity of nitrogen required for normal crop growth (Fig. 20). However, corn dry weight increases did not correlate with increases in the quantities of sludge or commercial fertilizer added to LOM soil. There was no further increase in dry weights at the first harvest when commercial nitrogen fertilizer was added in the quantity required for normal corn growth (175 lbs/acre) although twice that addition resulted in a 94% increase above the controls without addition of sludge or commercial fertilizer. Corn growth at the first harvest, as measured by dry weight increase, was stimulated to a greater extent with commercial nitrogen fertilizer addition than with tannery sludge (Figs. 20-23). The dry weights of corn were not changed at the first harvest with any addition of tannery sludge to high organic matter (HOM) soil. The dry weight was decreased in all soils to which sludge containing chromium at 10 times the initial concentration was added (Table 15). Corn did not grow in LOM soil amended with tannery sludge containing 100 times the initial concentration of chromium. Liming of HOM soil was required for corn growth when sludge containing 100 times the initial concentration of chromium was added to it, but the dry weights were reduced 94% at the first harvest in limed soil containing this quantity of added chromium (Fig. 24). Addition of only lime to LOM soil resulted in increased corn growth although the opposite effect was observed for HOM soil.

At the second harvest, the dry weights of corn grown in LOM soil amended with tannery sludge were significantly greater than those in the same soil amended with commercial nitrogen fertilizer (Figs. 25 and 26). The dry weights of corn increased also with increasing sludge addition to HOM soil (Fig. 25).

Corn growth, as measured by dry weight increases, was stimulated to a greater extent in LOM soil with tannery sludge than with commercial nitrogen fertilizer. At the second harvest, growth on soil containing sludge with 10 times the initial concentration of chromium was increased on both LOM and HOM soils (Table 15). There was corn growth at the second and third harvests on acid and limed HOM soil amended with tannery sludge containing chromium at 100 times the initial concentration. Corn dry weights were less on the acid than on the limed HOM soil containing added chromium. Growth increased at the second and third harvests on LOM soil which had only been limed, but the opposite effect was again observed on the HOM soil.

At the third harvest, dry weights of corn were increased in all LOM soils containing tannery sludge and in those LOM soils containing commercial nitrogen fertilizer equivalent to 87.5 and 175 pounds of nitrogen per acre, when compared to the control LOM soil with no sludge or commercial fertilizer additions (Fig. 27). The dry weights of plants grown in HOM soil were increased above the HOM control with no additions only when the sludge equivalent to twice the amount of nitrogen required for normal crop growth (350 pounds of nitrogen per acre) was applied. Dry weight of corn on control HOM soil was not statistically different from that on control LOM soil at the third harvest due to a decline in growth on HOM soil (Figs. 20, 25, and 27 and Table 15). The effects of using chromium supplemented tannery sludges on corn growth at the third harvest were similar to those observed at the second harvest.

Elemental composition. At the first harvest of corn, the concentrations of nitrogen, sulfur, and manganese increased in plants with increasing commercial nitrogen fertilizer and tannery sludge in low organic matter (LOM) soil (Table 23). The concentrations of calcium, magnesium, boron, and iron increased in corn with increasing additions of tannery sludge to LOM soil, but lead and nickel decreased. The concentration of calcium increased with increasing tannery sludge addition to high organic matter (HOM) soil at the first harvest. The concentration of manganese decreased in limed HOM soils while that of zinc decreased when both HOM and LOM soils were limed. Addition of tannery sludge containing 10 times the initial concentration of chromium to LOM soil (1.47 g Cr/kg soil) resulted in a greater concentration of chromium in plants grown in this soil mixture although the increase was not proportional to the addition of the element. The concentration of chromium in corn grown in HOM soil amended with sludge containing 10 times the initial amount of the element was not statistically greater than that in control plants.

The concentrations of calcium, magnesium, chromium, copper, and manganese in the second harvest of corn were greater than those observed at the first harvest while those of boron and lead were less than those observed at the first harvest (Table 24). The concentration of nitrogen at the second harvest increased in corn as the amounts of commercial nitrogen fertilizer and tannery sludge increased in LOM soil. The concentrations of phosphorus and magnesium increased in corn plants grown on HOM soil as tannery sludge increased. The concentration of magnesium decreased with the organic carbon content of the LOM and HOM soil mixtures. The concentration of calcium in corn increased as sludge addition to LOM soil increased. The concentration of potassium decreased with sludge addition to the HOM soil and when the LOM and HOM soils were limed. ~~The concentrations of iron and zinc were less in corn grown on limed HOM soil with a neutral pH than on acid LOM soils~~. The concentration of manganese in plants grown on acid HOM soil was less than that in plants grown on acid LOM soil and decreased in both soils when lime was added.

The concentrations of chromium in the second harvest of corn grown on HOM soil were less than those in plants grown on LOM soil. The concentration of chromium in corn grown on acid LOM soil amended with tannery sludge containing 10 times the initial concentration of chromium, was not statistically different from that in plants grown on the same soil without added chromium. The concentrations of chromium in corn grown on acid HOM soil amended with tannery sludge containing 10 and 100 times the initial concentration of chromium were not different from those in plants grown on the same soil without added chromium. The concentration of chromium in plants grown on limed HOM soil receiving 100-fold additional chromium was 2.5 times that in plants grown on limed HOM without added chromium.

The concentrations of cadmium, copper, iron, and nickel were higher at the third harvest of corn plants than at the second, but the concentration of potassium was lower (Tables 24 and 25). When the concentrations of the elements were compared within the third harvest it was found that nitrogen increased in plants with tannery sludge addition to LOM soil after an initial decrease below the corresponding LOM control (Table 25). The concentration of sulfur in corn plants grown on acid LOM soil increased with commercial nitrogen fertilizer and tannery sludge addition to the soil; the concentration of sulfur also increased in limed HOM soil containing 16.0 g Cr per kg soil (100-fold addition of chromium to sludge). The concentration of calcium increased in plants with tannery sludge addition to LOM soil but was significantly lower in plants from soil that received lime and chromium supplemented sludge. The magnesium concentration was greater in plants from limed LOM and HOM soils which received tannery sludge than in plants from any other soil mixture. Boron increased in plants from acid LOM soil with commercial nitrogen fertilizer addition. The concentration of cadmium in plants from soils containing chromium supplemented sludge was higher than that in plants from any other soil mixture.

The concentration of chromium was lower in plants harvested from limed soils than in those from corresponding acid soils. The concentration of chromium did not vary consistently with any other treatment of either LOM or HOM soil and the highest concentration of the element occurred in plants from LOM soil amended with 175 pounds of commercial nitrogen per acre, a soil which never contained tannery sludge.

The concentrations of copper and zinc decreased in corn as tannery sludge addition to LOM soil increased. The concentration zinc was also lower in plants grown on limed soil than on the corresponding acid soils. The concentration of manganese increased as the quantity of sludge in the LOM soil increased but did remained below the control concentration. Manganese concentration decreased in plants from HOM soil as the quantity of tannery sludge added increased. Manganese concentration also decreased in plants following addition of lime to LOM and HOM soils.

The concentration of calcium increased throughout the experiment in plants from the limed soils except those that received chromium supplemented tannery sludge (Tables 23-25). The concentration of manganese increased with each harvest of plants grown on acid soils which did not receive chromium supplemented sludge. The concentration of chromium increased throughout the experiment in plants from HOM and limed LOM soils. The concentration of iron increased in plants grown on limed soils as the experiment continued.

DISCUSSION

The results of this experiment show that the dry weights of corn, bush beans, and tall fescue can increase as a result of tannery sludge application to soils. The concentrations of chromium (15.9 g/kg dry sludge) and nitrogen (2.9%) in the sludge were approximately half that previously reported (Conrad, et al., 1976). It is expected that the concentrations of elements in tannery sludges will vary with the source of the sludge. This will make quantitative chemical analyses imperative before addition of tannery sludge from any given source to agricultural land.

The soils to which tannery sludge was to be added were virtually identical with respect to pH before any additions were made (Table 1). However, the mean concentration of organic carbon in the HOM (high organic matter) soil was more than three times that in the LOM (low organic matter) soil. More than twelve times as much soluble nitrogen was available for plant uptake in the HOM soil than in the LOM soil. Soluble phosphorus, magnesium, and potassium were each of greater concentration in the HOM than in LOM soil. Thus, when the nutrient status of the two soils are compared the HOM soil appears much more suitable for growth of agricultural plants than LOM soil.

The decreased concentrations of soluble manganese and soluble phosphorus in soils following lime and/or tannery sludge addition is likely due to a change in soil pH because the solubility of compounds of both elements will decrease when pH is increased. The reduced growth of bush beans in soil containing lime and/or sludge may be due to reduced uptake of manganese and/or phosphate. Few compounds of manganese (except sulfates and sulfides) are soluble in neutral aqueous solution whereas many of the same compounds are soluble in acid.

The addition of tannery sludge to soils increased the concentration of some nutrients in the soils. For example, nitrogen and calcium which are plant macronutrient elements were added with the sludge and their presence would be expected to improve plant growth in nutrient deficient soil. The concentrations of total nitrogen and calcium did not always appear to increase when sludge, commercial fertilizer, or lime were added to soil because the addition was very small when compared to the concentrations of these elements already in the soil. Nitrogen is often growth-limiting in soils but the concentration of soluble nitrogen decreased inconsistently throughout the duration of this experiment. Plant growth however continued to decrease in a manner indicating depletion of a nutrient element(s) in the soil. The concentration of only soluble potassium consistently decreased and this decrease occurred only in the soil used to grow tall fescue. It is therefore difficult to correlate changes in plant growth within a treatment in this experiment with changes in the concentration of nutrient elements in the soil over a period of time.

The more rapid loss of ammonia from tannery sludge amended soil after 23 weeks than from soil amended with commercial fertilizer indicates that a greater portion of ammonia in the sludge is in the NH_3 (dissolved gas) state as opposed to the ammonium salt in the commercial fertilizer. This may also account for the increases in nitrates and nitrites after 23 weeks in soil amended with commercial fertilizer and planted with bush beans and corn whereas oxidized nitrogen compounds did not increase in tannery sludge amended soil. The tannery sludge may also have inhibited growth of nitrifying bacteria in soil which contained sludge and therefore allowed ammonia to be released from the soil before oxidation of the nitrogen could occur. However, these explanations do not account for the lack of nitrate and nitrite in the soil planted with tall fescue. Sampling technique may account for the difference since the soil planted with tall fescue was not removed from the polyethylene container before soil specimens were taken for analysis (see Methods).

Chromium is not considered a nutrient element for plant growth although some beneficial effects of the element in nutrient media have been reported (Bertrand and De Wolf, 1965; Bertrand and De Wolf, 1968). The toxic effects of trivalent chromium are also documented although it is less toxic than hexavalent chromium (Mortvedt and Giordano, 1975; Wallace et al., 1976; Skeffington et al., 1976).

The concentration of chromium in soil is reported to range from traces to 250 ppm (Mertz, 1969). The chromium concentration in the low organic matter (LOM) and high organic matter (HOM) soils used in this experiment were within this range. The chromium concentration remained within this range when one-half the quantity of tannery sludge equivalent to the available nitrogen required for normal crop growth was added. Final analysis of the soils at the end of the experiment revealed that the concentration of chromium in LOM soils amended with the quantity of sludge equivalent to the amount of nitrogen required for normal crop growth was also less than 250 ppm.

The concentration of chromium in plant vegetative parts are reported to range from 10 to 1000 ppb (Mertz, 1969). Other reports have given ranges of 2, 1.3-2.0, and 0.4 ppm chromium in the above-ground organs of perennial ryegrass, corn, and bush beans, respectively, grown in soil without chromium addition from any source (Bolton, 1975; Mortvedt and Giordano, 1975; Wallace et al., 1975). Chromium in plant tops ranged from less than 1.03 to 10.5 ppm in plants grown on soils without chromium or tannery sludge addition in this experiment (Tables 17-25). Chromium in the tops of plants grown on soil amended with tannery sludge equivalent to 2 times the amount of fertilizer nitrogen required for normal crop growth ranged from 1.48 to 8.6 ppm. Maximum chromium concentrations of 11.0 and 20.5 ppm were measured in the tops of bush beans grown on soil amended with tannery sludge containing chromium at 10 and 100 times, respectively, the initial chromium concentration in the sludge (Table 22). The chromium concentration observed in plants in this experiment were higher than those reported in other experiments although concentrations of the element in the soil were within the reported range. Many factors affect the rate of chromium uptake by plants. These include soil physical and chemical properties such as pH and CEC, solubility of the chromium compound, and the species of plant. Thus, the conditions of this experiment may have favored chromium uptake as well as uptake of other heavy metals such as cadmium, copper, and nickel.

Although the concentration of soluble chromium decreased in LOM and increased in HOM soils planted with corn and bush bean containing additional salt after 23 weeks, it was consistently lower in HOM soil. The increase in soluble chromium in LOM soil planted with tall fescue may have been due to technique which allowed the other soils to lay fallow and exposed to air before sampling whereas the tall fescue soil could not be so manipulated (see Methods). The liming effect of tannery sludge applied to acid soil continued throughout the experiment, however, LOM soil to which tannery sludge containing 100 times the initial concentration of chromium was added became more acid with chromium addition and lime did not prevent the LOM soil from becoming acid. The high concentration of ammonia in HOM soil amended with tannery sludge containing 100 times the initial concentration of chromium was observed in the final analyses of the HOM soils used to grow all these plant species

(Tables 7, 10 and 13). These soils were apparently made more acid by the chromium addition and the increased acidity have catalyzed deamination of amino acids and proteins in the soil and tannery sludge since the HOM was 1.31 per nitrogen (Table 1).

It is not known whether or not the chromium compounds present in the soil at the end of this experiment will have the same or similar properties to the chromium compounds that will exist after 100 years of tannery sludge application. However, if the chromium compounds are similar it can be concluded that the soil will no longer be useable for growing plants. The soil will also exhibit diminished capacity for growing crops similar to corn and bush beans after 10 years of tannery sludge addition if the chromium remains in the soil.

The increasing concentration of soluble salts of elements such as sodium and boron in soils with tannery sludge addition concomitantly with increasing soil electroconductivity indicates that a high soluble salt concentration may have influenced the growth of the experimental plants. The plants' response to nitrogen and other nutrient element uptake would, however, obscure any beneficial effects obtained from the soluble salts and the effects of chromium would likewise obscure toxic effects.

All three plant species were adversely affected by the greater chromium addition. This result indicates that chromium inhibits plant growth when present in the soil at concentrations that approximate the result of 100 years of tannery sludge application (Table 15). The growth of corn and bush bean but not tall fescue are always inhibited when 10 years' sludge application is simulated. This is assuming that chromium hydroxide sulfate (trivalent chromium) utilized in this experiment and chromium oxide (trivalent chromium) already in the sludge are chemically similar and the chemical and physical properties of these compounds do not change upon addition to the soil. It is also assumed that the properties of the chromium do not change over 10 to 100 years in the soil. It cannot be concluded that plants grown on soils amended with the chromium supplemented tannery sludges will be identical to plants grown on the same soils that have been amended annually with tannery sludge. However, it can be concluded that 1,300 to 28,000 mg total chromium and 0.3 to 8,720 mg soluble chromium per kg dry soil can reduce and/or prevent seed germination and plant growth.

Lack of a statistically significant decrease in bush bean seedling emergence after the third planting in limed HOM soil amended with chromium supplemented sludge indicates that a neutral soil reaction and presence of organic matter will decrease some of the harmful effects of chromium in soil (Table 14). Organic matter and a neutral pH would cause chromium to decrease in aqueous solution by making it less soluble and therefore less available for plant uptake (Bartlett and Kimble 1976). Similar effects were also observed in corn and tall fescue seedling emergence although a significant decrease in corn seedling emergence was observed after the first planting when the HOM soil was limed before adding sludge with 100 times the initial concentration of chromium. This effect was not seen at the second and third plantings of corn. More chromium had been added to the soils for corn growth because this soil received more tannery sludge (Table 4). The large sludge addition was necessary because of the high nitrogen requirement of corn (Extension Service, 1978). The higher concentration of chromium may have decreased corn seedling emergence more than that of the other plants. The plant available chromium had decreased at subsequent harvests (Tables 11-13), which may have allowed more corn to sprout.

The reduced growth of the first cut of tall fescue and the first harvest of corn in tannery sludge amended LOM soil in comparison to growth in commercial nitrogen fertilizer may have been due to insufficient plant available nitrogen in the sludge. Therefore addition of larger quantities of sludge would be expected to improve plant growth as long as the amount of chromium (and other toxic materials) added did not exceed levels that are harmful to plants. The experiment with bush beans was complicated by the decreased growth of plants in limed soil. The results of the first harvest of bush bean were, however, similar to those of the first corn and fescue harvests.

Only one addition of tannery sludge or commercial nitrogen fertilizer was made in the experiment, but the dry weights were greater when corn and fescue were grown on sludge amended soil than on that amended with commercial nitrogen fertilizer at the second harvest (Figs. 6, 25, and 26). The stimulation of growth obtained with tannery sludge at the first harvest persisted longer than that with commercial fertilizer and was more pronounced at the second harvest. The nitrogen from commercial fertilizer is not renewable without further addition while that from tannery sludge is renewed by mineralization of sludge nitrogen. Therefore, tannery sludge is a more persistent source of nitrogen than commercial nirogen fertilizer. It may be concluded that mineralization of sludge supplied nutrients, particularly nitrogen, for plant growth. However, the greater growth of corn and fescue on sludge amended at the second harvest may also be due in part to attenuation of toxic constituents in the sludge. Growth in tannery sludge amended soil may have been delayed by growth-retarding materials in the sludge, such as gaseous ammonia and ethylene, which must dissipate before plants can grow rapidly in the vegetative stages (Wollan <u>et</u> <u>al</u>. 1978).

The decreased growth of bush beans with increasing tannery sludge additions is not likely due to nitrogen saturation since growth in LOM soil with no sludge continued to increase with the addition of commercial nitrogen fertilizer (Fig. 9). The decreased growth may be due to the liming effects of the sludge or the toxic effects of materials which inhibit bush bean growth more than that or corn and tall fescue. Metallic cations that are not in solution when the soil has a neutral or basic pH will be mobilized for plant uptake in acid soil. Bush beans may require a micronutrient, for example soluble manganese, which is available in sufficient quantity only in acid soil (Tables 8, 9, and 10). This could explain the greater growth in acid soils. However, this also indicates that addition of tannery sludge with a pH of 10 or more to soil would tend to decrease growth of the beans either directly or indirectly and nullify some of the beneficial effects of the added nitrogen from this source.

The decrease in bush bean dry weights observed after sludge addition to HOM soil may be due to a decrease in soil acidity and/or toxic effects of the sludge (Fig. 9). The increase in growth above the control observed after tannery sludge addition to LOM soil indicates that the sludge supplied ~~the~~ an essential nutrient element(s), probably nitrogen, which is growth limiting since growth also increased with commercial nitrogen fertilizer addition. Comparison of the data in Figure 9 with that in Figure 14 shows the growth stimulation in LOM soil obtained with tannery sludge addition persisted longer than that with commercial fertilizer. The situation is the same as that with tall fescue in that nitrogen from commercial fertilizer is not renewable without further addition while that from tannery sludge is renewed by mineralization of sludge nitrogen.

The decline in nitrogenase activity in bush bean nodules following tannery sludge and commercial nitrogen fertilizer addition indicates that nitrogen was available in the soil with both additions since available fixed nitrogen will inhibit biological reduction of atmospheric nitrogen (Hardy et al., 1973). Nitrate, ammonia and urea will decrease nitrogen fixing activity in soybean. Similar effects may be expected in bush bean which is also a leguminous nitrogen fixing plant. Toxic effects of the sludge may account for the greater decline in nitrogenase activity in plants grown on soil amended with tannery sludge. Activity declined as the experiment proceeded and plant nutrients were depleted in the soil. The low activity in limed soil may be due to lack of root growth since bush beans grow less in limed soils.

The presence of toxic elements in the sludge may explain the lack of response by corn to increasing sludge addition. It is not likely that addition of tannery sludge elevates the pH to a value at which an essential and limiting micronutrient element ceases to be available for corn uptake since liming the soil did not decrease the amount of growth (Table 15). Nitrogen saturation in the soil cannot be concluded since growth increased with increasing quantities of commercial nitrogen fertilizer added to LOM soil and was greater at the first harvest than that produced by the sludge. Growth was not changed with addition of sludge to HOM soil, indicating that nitrogen was not growth limiting in this soil at the first harvest. Observation of the growth of corn in HOM (high organic matter) soil at the second and third harvests shows that the sludge is a source of a plant nutrient element or elements, since growth increased in proportion to sludge added. It is also possible that the presence of the organic matter might have reduced some of the toxic effects of the sludge and allowed the dry weight of corn to increase with tannery sludge addition to the HOM soil.

Essential nutrients in the tannery sludge may have enhanced growth of tall fescue sufficiently to obscure chromium effects in LOM soil amended with sludge containing 10 times the initial concentration of the element so that there was no significant dry weight reduction. The same nutrients may also be present in HOM soil with or without sludge addition since the plant dry weight is greater in HOM than LOM soil (Table 15). The toxic effects of chromium might then be seen without symptoms of nutrient deficiency. It is also possible that tall fescue may be less sensitive to chromium than corn or bush beans which failed to grow normally in LOM soil amended with tannery sludge containing 10 times the initial chromium concentration.

All three species grew more nearly normal in HOM soil with the same amount of chromium added to it. The organic matter in the HOM appeared to remove the chromium from solution and allow the plants to grow in this soil. The element remained in solution in LOM soil at a sufficiently high concentration to prevent plant growth whereas organic matter removed chromium from solution (Tables 5-13). The organic matter in the acid HOM soil apparently removed enough chromium from solution to allow some bush beans to grow when 100 times the amount of the element present initially in sludge was added to it. Corn seedlings sprouted at this concentration but did not grow appreciably.

The low organic matter content of LOM soil allowed chromium to remain in solution at a sufficiently high concentration to prevent seed germination and plant growth when tannery sludge containing 100 times the initial chromium concentration was added. Liming of soil, as well as a high organic matter content is required for plants to grow when sludge containing chromium at 100 times the initial concentration was added to soils. Liming will raise the pH of soil and cause precipitation of chromium salt from solution (Bartlett and Kimble 1976). Salt crystals indeed formed at the surface of limed LOM and HOM soils. The removal of the element from solution would be expected to prevent its uptake by plants. Thus liming of soil to which chromium has been added will allow plant growth with reduction of some of the toxic effects provided the chromium concentration is not so high as to inhibit seed germination and sprouting of seedlings.

When the first cutting of tall fescue was analyzed the result indicated that absorption of nutrient elements such as nitrogen and phosporus and the potentially hazardous element chromium were dependent upon the concentration of their soluble compounds in the soil solution. An exception to this would be the high concentrations of nitrogen and sulfur in plants from limed HOM soil containing the 100-fold addition of chromium; the high concentrations of nitrogen and sulfur are likely due to the greatly reduced growth of these plants at the first cutting. The results of the second cutting were similar to those of the first although many of the nutrient elements were lower in concentration in the plant leaves (Table 18). Depletion of nutrients by the crop previously grown may account for the decrease in nutrient element concentration. Further decreases in the concentrations of the macronutrient elements nitrogen and potassium at the third cutting are likely the result of nutrient depletion in the soil.

There was also an increase in the concentrations of trace elements and heavy metals such as copper, lead, and nickel in plants from the third cutting of tall fescue. The increase in concentration of such elements may have occurred as a result of the nutrient deficient status of the soil. Trace elements with chemical properties similiar to the nutrient metal cations which are deficient in the soil solutions may have been absorbed by the plants instead of the nutrient elements. This explanation is presented because neither the concentrations of the soluble trace element compounds in the soil nor the soil pH changed sufficiently to account for the increased heavy metal uptake (Table 19).

A high concentration of chromium in the soil may decrease calcium uptake by tall fescue. This effect was observed in all three cuts but was more pronounced in plants from the third cut (Tables 17-19). Although the concentration of chromium did not increase in proportion to the concentration of the element in the soils increases were observed. These results indicate that there is a limit to the amount of tannery sludge that can be applied to soils before chromium uptake becomes excessive in tall fescue. This limit will depend on the concentration of chromium in the sludge relative to that of nitrogen. The agricultural value of tannery sludge will therefore depend on the ratio of nitrogen concentration to the concentration of hazardous materials in the sludge. Sludge with a higher mineralizable nitrogen content ~~will~~ can ~~need to~~ be applied to soil in smaller amounts than that with a lower content. Contamination of the soil with hazardous material will then be decreased.

The results of bush bean plant analysis suggest that decreases in growth as a result of tannery sludge addition to the soil are partly due to the liming effect of the sludge. The high negative correlation ($R = -0.90$) of manganese concentration in plants with tannery sludge addition suggest that the element is made less available to plants by lime addition to soils. There were indeed decreases in soluble manganese in soils following lime and sludge addition although the decreases did not always correlate with the sludge addition (Tables 8-10).

Analysis of the soils after the second bush bean harvest revealed more nitrates and nitrites in sludge amended soil than in that amended with commercial fertilizer (Table 9). The greater growth of bush beans in sludge amended soil may be attributed to higher soil soil nitrate concentration.

No conclusions relative to the effects of tannery sludge could be drawn from the third harvest of bush bean. Results of the third harvest were complicated by very poor growth of the plants because of the decreased nutrient value of the soil following the repeated use of it. Cobalt concentrations were not measured in this experiment although cobalt is required by legumes to fix atmospheric nitrogen. Cobalt deficiency would prevent nitrogen fixation and growth in nitrogen deficient soils. However, growth of bush beans was poorest ~~worst~~ in HOM (high organic matter) soil which was not nitrogen deficient (Table 10). The conditions limiting growth of bush bean in this experiment are not immediately known.

The increasing concentrations of nutrient elements in corn at the first harvest as a result of tannery sludge addition is indicative of the potential of tannery sludge to supply nutrients for plant growth. Also, a liming effect is suggested in the decrease of heavy metals such as lead and nickel in corn following sludge and lime additions. The results also indicate that chromium is not readily available to plants when tannery sludge has been applied to soils with a high organic matter content. Chromium is more available to plants grown in soil of a low organic matter content. Tannery sludge will enhance the growth of corn in nutrient deficient soil and can therefore be considered as an alternative to commercial fertilizer. However, the results also indicate 10 years' application of tannery sludge with the chromium content of the sludge used in this experiment can lead to significantly greater chromium concentrations in the tops of corn plants than would be found if sludge were not used.

Both tannery sludge and commercial nitrogen fertilizer were sources of nitrogen for corn at the second harvest as the dry weights of the plants increased with addition of each to LOM (low organic matter) soil. Neither the concentration of available nitrogen in the soil nor the concentration of nitrogen in plants were greater at the second harvest of corn from sludge amended soil than at the first. This suggests that another nutrient element, for example, calcium or phosphorus may have become more available to plants grown in sludge amdended soil to cause them to grow more than those grown in soil amended with commercial fertilizer.

Chromium uptake in corn from the second harvest did not increase significantly as a result of addition of the element to LOM soil with sludge containing 10 times the initial amount of chromium. Ten-fold more chromium could be added to HOM (high organic matter) soil without a statistically significant increase in concentration of the element in corn. The concentrations of trace metals such as lead, cadmium, and nickel did not increase in corn plants with tannery sludge addition and remained at barely detectable levels regarding soil treatment (Table 24).

Poor growth of corn plants resulting from nutrient depletion in the soil complicated the third harvest. Few conclusions can be drawn from these data that are relevant to tannery sludge effects on corn growth. The concentrations of the elements in the plants remained nearly the same as in earlier harvests probably because the corn dry weights were decreased.

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Figure 1

The effects of tannery sludge and commercial nitrogen fertilizer on dry matter yield of tall fescue at the first cut. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 151%.

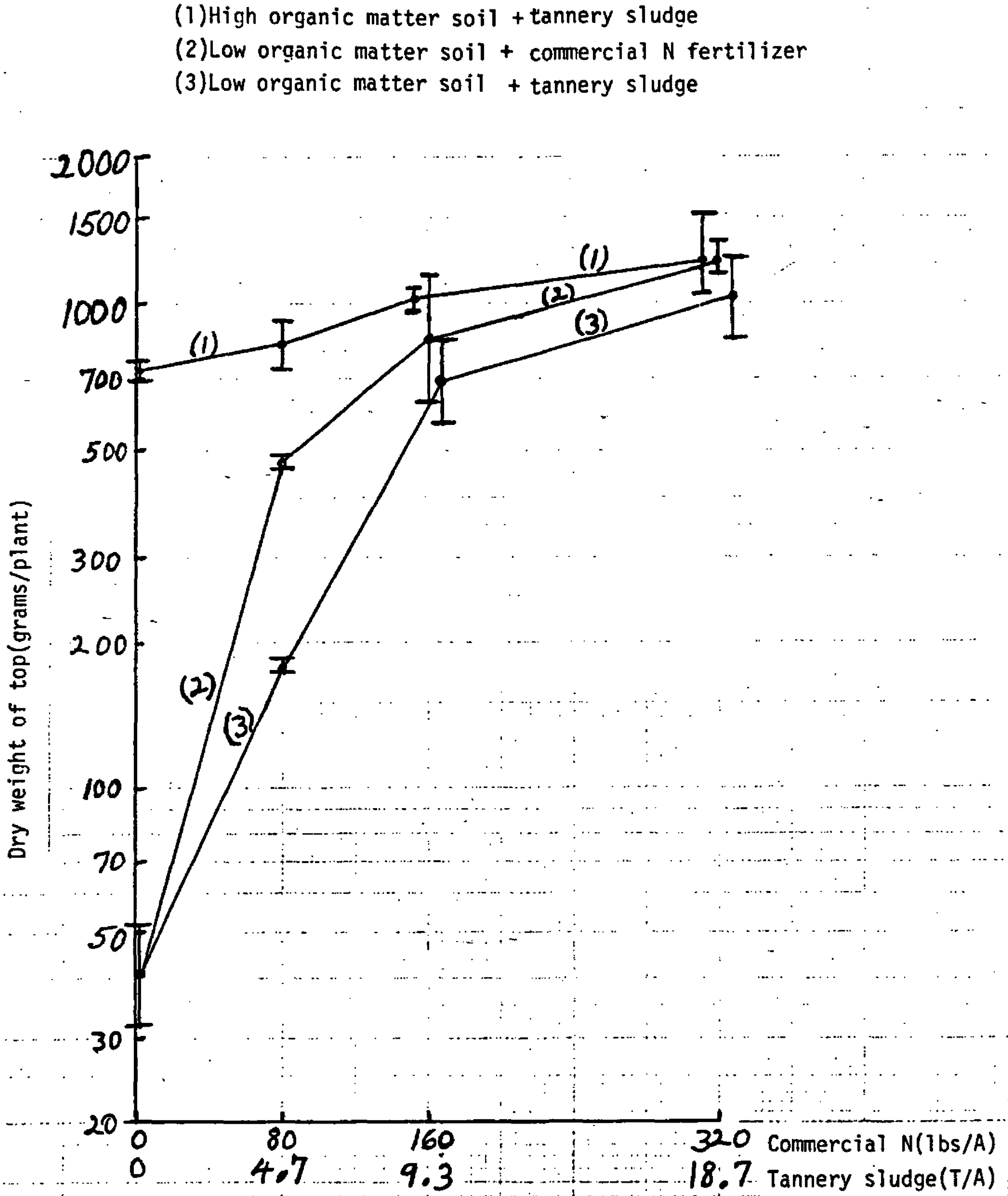

Figure 1

Semi-Logarithmic
3 Cycles x 70 to the inch

Figure 2

The effect of commercial nitrogen fertilizer on the first cut of tall fescue in LOM (low organic matter) soil. The two containers on the left contain plants grown in control LOM soil without fertilizer and those on the right contain plants grown with the equivalent of 160 pounds of commercial nitrogen fertilizer per acre.

Figure 2

Figure 3

The effect of tannery sludge on the first cut of tall fescue in LOM (low organic matter) soil. The two containers on the left contain plants grown in control LOM soil without tannery sludge and those on the right contain plants grown in the equivalent of 9.3 tons of tannery sludge (160 lbs. available N) per acre.

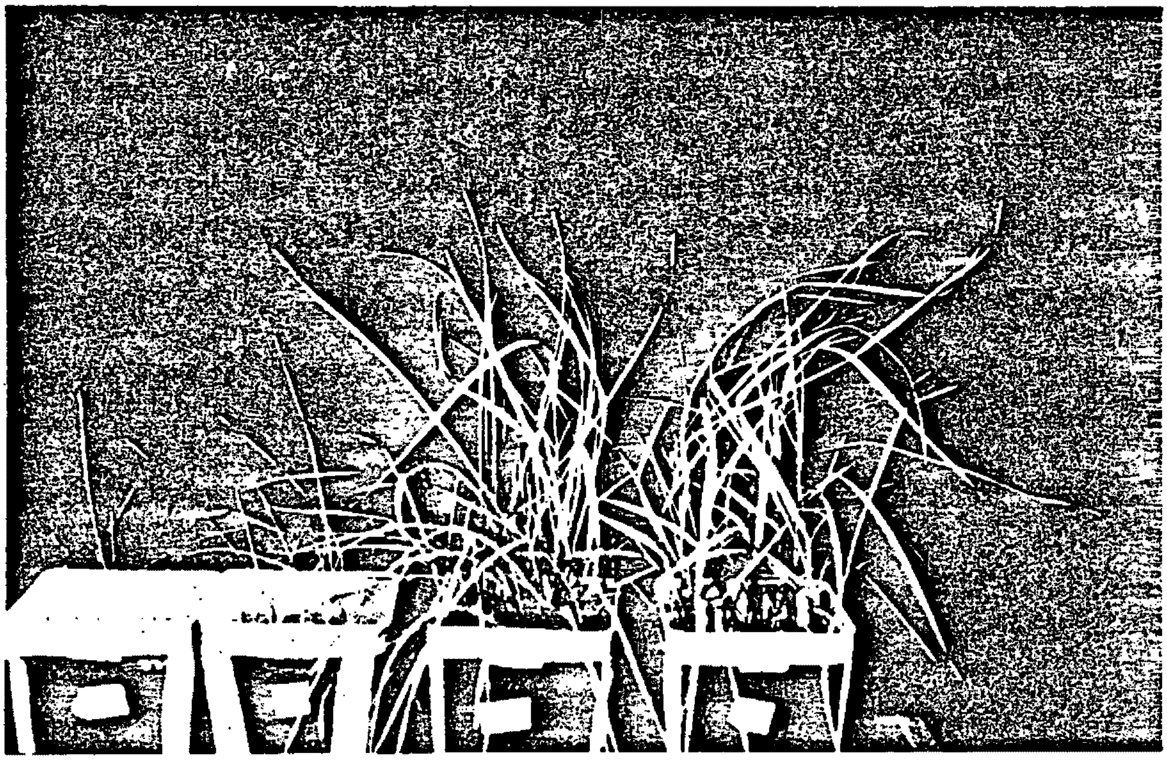

Figure 3

Figure 4

Comparison of the effects of commercial nitrogen fertilizer and tannery sludge on the first cut of tall fescue in LOM (low organic matter) soil. The two containers on the left contain plants grown with the equivalent of 160 pounds of commercial nitrogen per acre and those on the right contain plants grown on 9.3 tons of tannery sludge (160 lbs. available N) per acre.

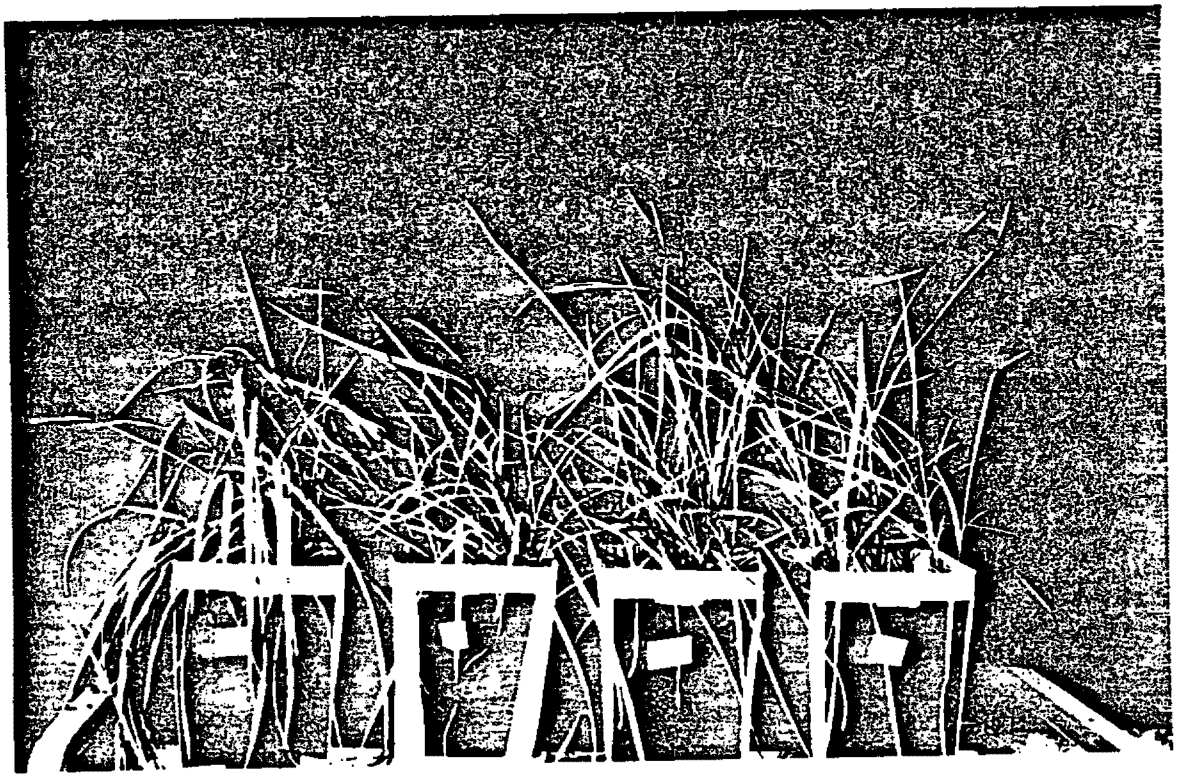

Figure 4

Figure 5

The effect of chromium on the growth of tall fescue. Plants on the left were grown in HOM (high organic matter) soil containing 14.6 g chromium per kg dry soil while those on the right were in control soil without added chromium.

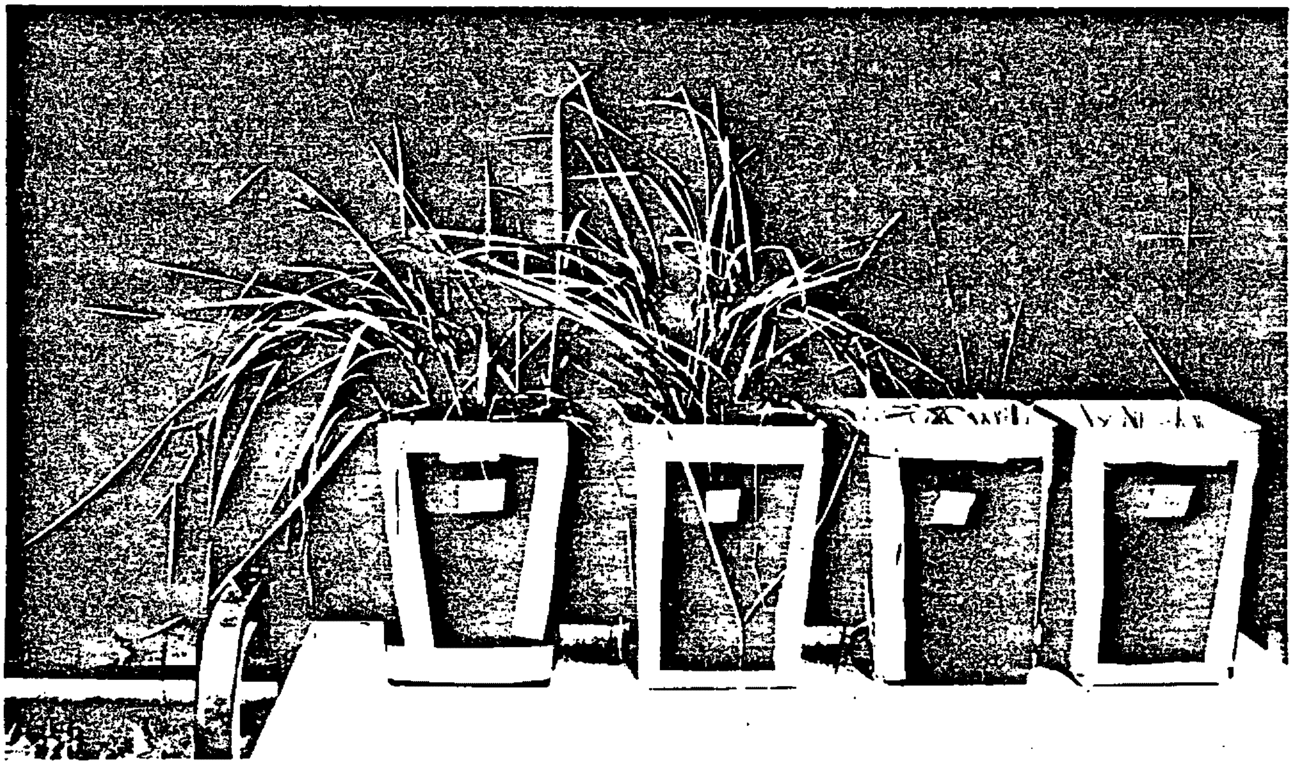

Figure 5

Figure 6

The effects of tannery sludge and commercial nitrogen fertilizer on dry matter yield of tall fescue at the second cut. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 66%.

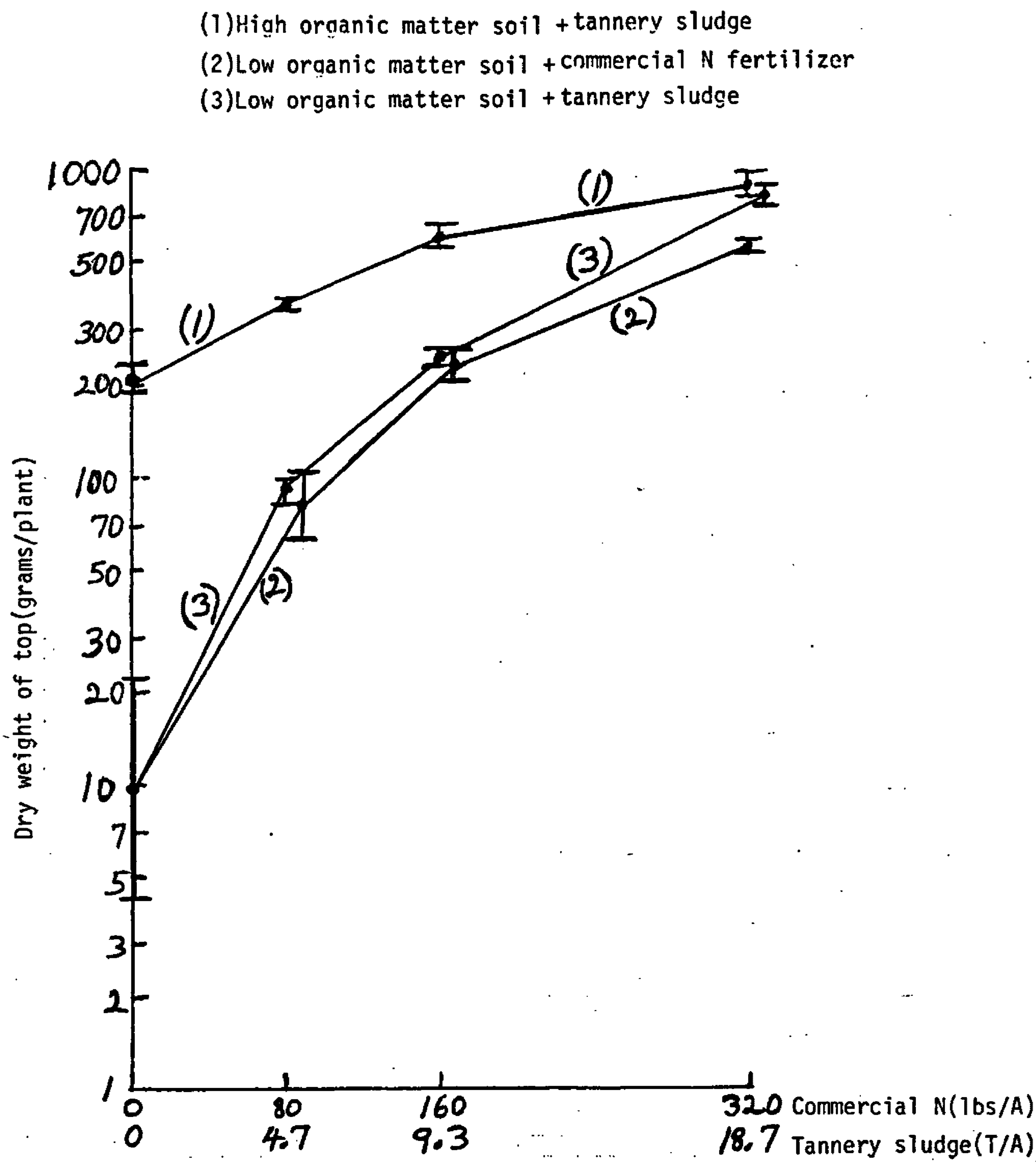
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Dry weight of top(grams/plant)
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0
80
160
320
Commercial N(lbs/A)
0
4.7
9.3
18.7
Tannery sludge(T/A)
(1)
(2)
(3)

Figure 6

Figure 7

Comparison of the effects of commercial nitrogen fertilizer and tannery sludge on the second cut of tall fescue. The plants in the left container were grown in LOM (low organic matter) soil amended with the equivalent of 160 pounds of commercial nitrogen per acre and those on the right were grown with 9.3 tons tannery sludge (160 lbs. available N) per acre.

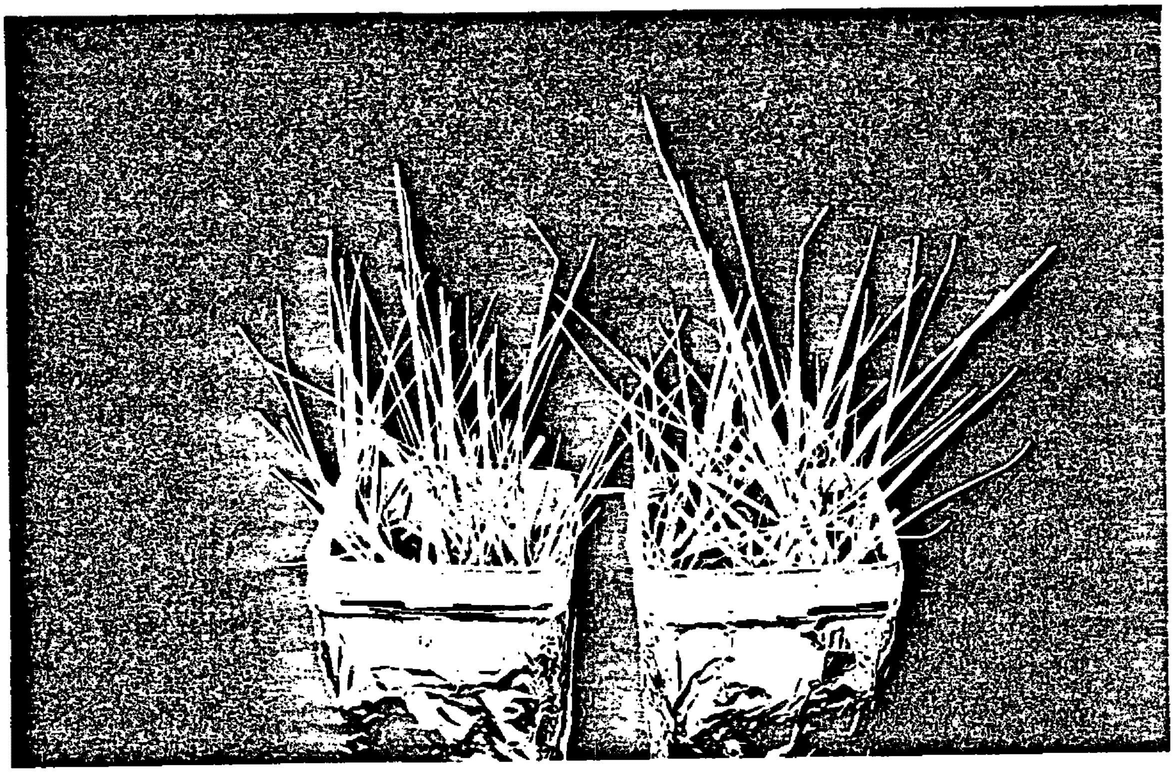

Figure 7

Figure 8

The effect of tannery sludge and commercial nitrogen fertilizer on dry matter yield of tall fescue at the third cut. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 20%.

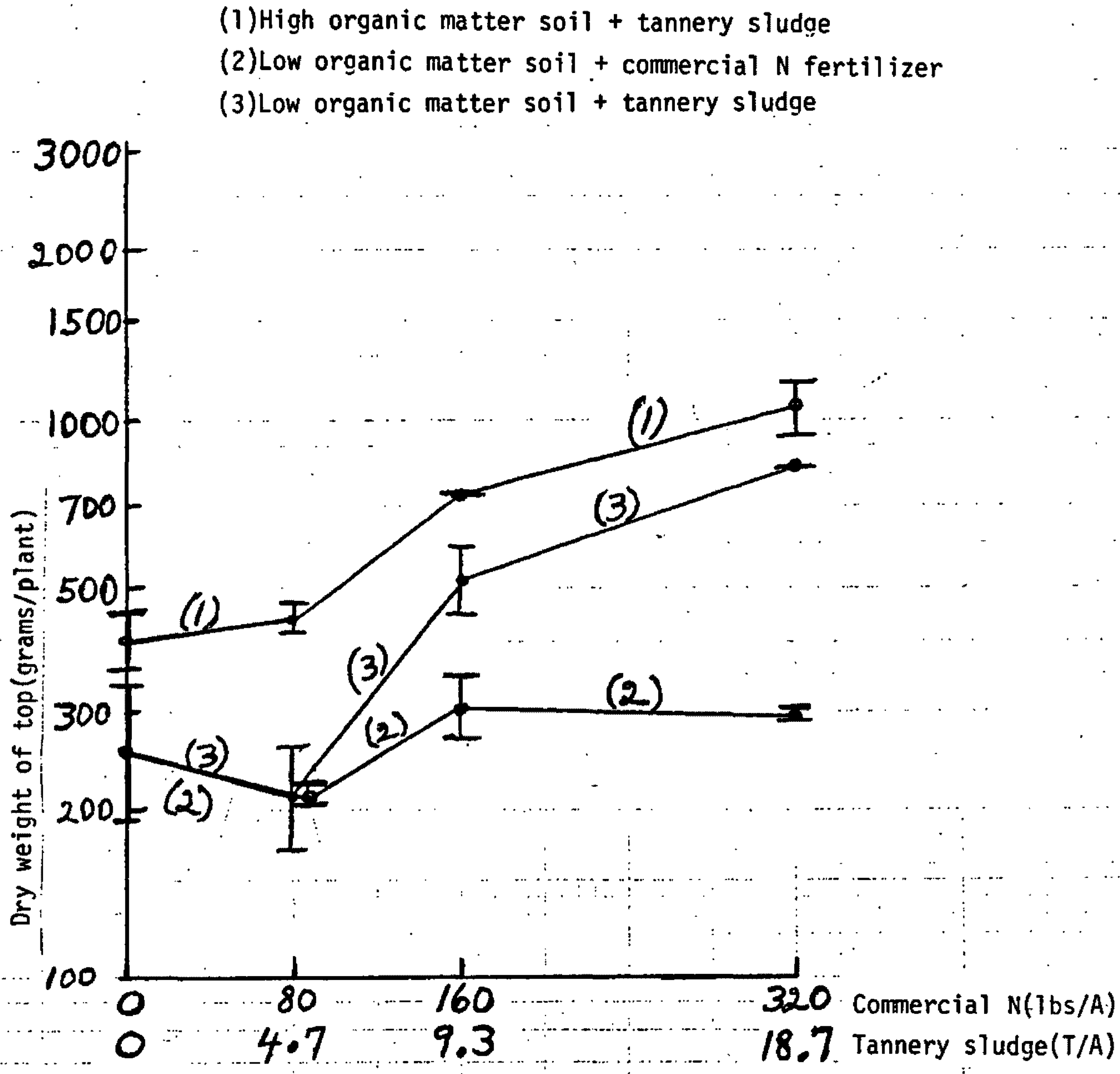
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Dry weight of top(grams/plant)
3000
2000
1500
1000
700
500
300
200
100
(1)
(2)
(3)
0
80
160
320
Commercial N(lbs/A)
0
4.7
9.3
18.7
Tannery sludge(T/A)

Figure 8

Figure 9

The effects of tannery sludge and commercial nitrogen fertilizer on growth of bush beans at the first harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 46%.

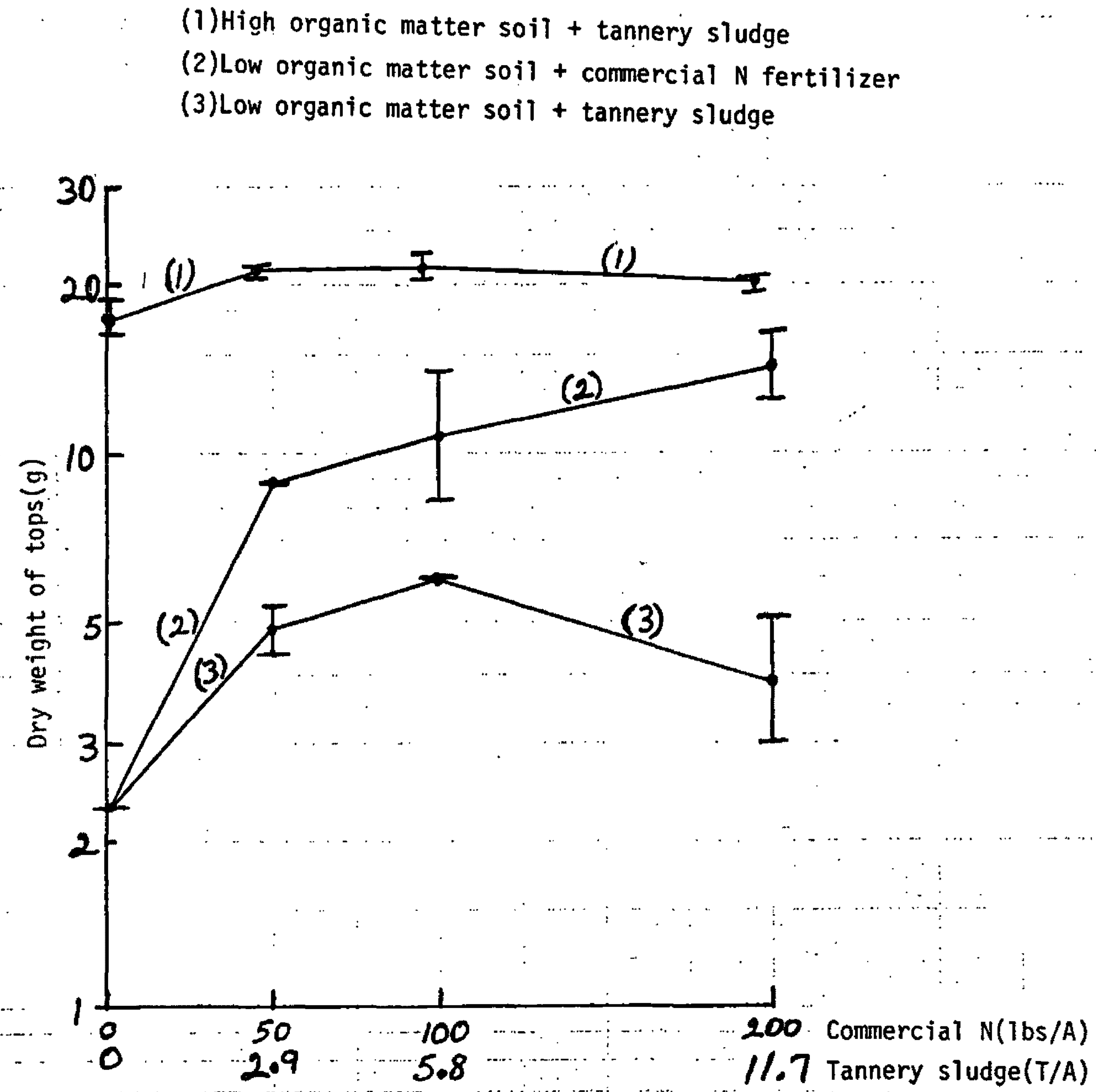
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Dry weight of tops(g)
30
20
10
5
3
2
1
(1)
(2)
(3)
0
50
100
200
Commercial N(lbs/A)
0
2.9
5.8
11.7
Tannery sludge(T/A)

Figure 9

Figure 10

The effect of commercial nitrogen fertilizer on the first harvest of bush beans in LOM (low organic matter) soil. The two containers on the left contain plants grown in control LOM soil without fertilizer and those on the right contain plants grown with the equivalent of 100 pounds of commercial nitrogen fertilizer per acre.

Figure 10

Figure 11

The effect of tannery sludge on the first harvest of bush beans in LOM (low organic matter) soil. Plants in the two containers on the left are in control LOM soil without tannery sludge and those on the right are in LOM soil with the equivalent of 5.8 tons of tannery sludge per acre.

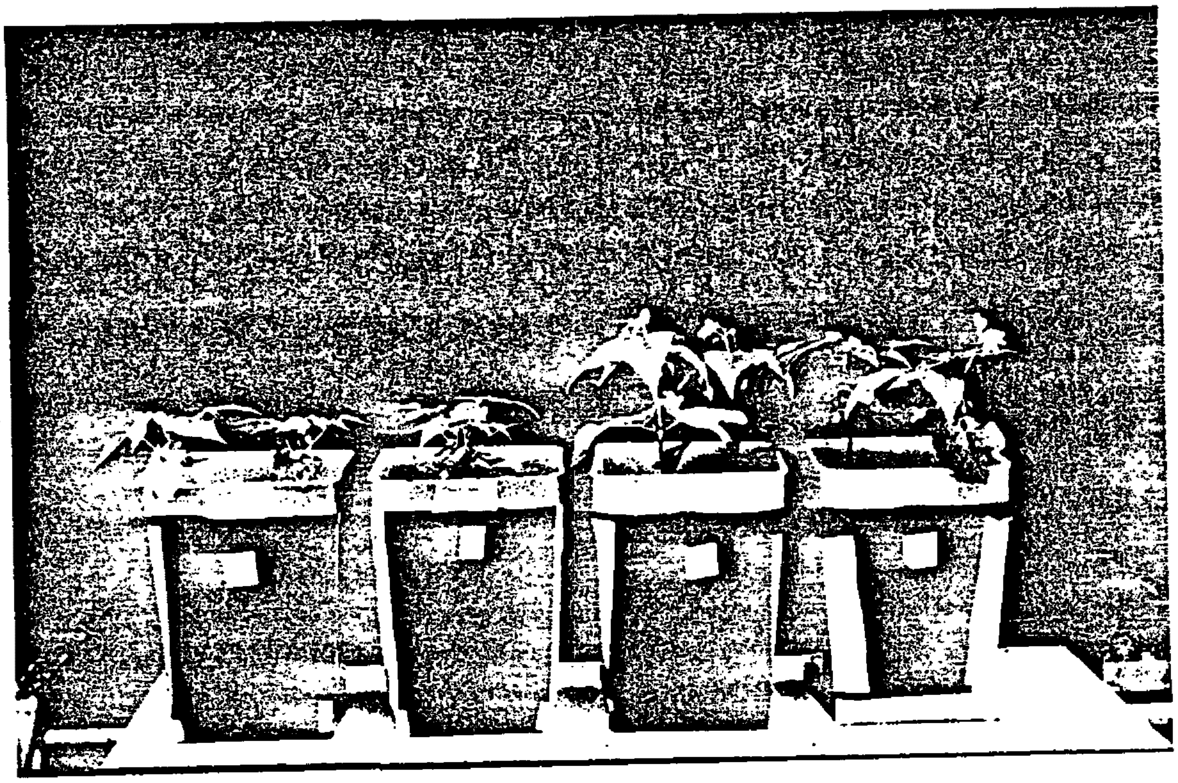

Figure 11

Figure 12

Comparison of the effects of commercial nitrogen fertilizer and tannery sludge on the first harvest of bush beans in LOM (low organic matter) soil. The two containers on the left contain plants grown with the equivalent of 100 pounds of commercial nitrogen per acre and those on the right contain plants grown on 5.8 tons of tannery sludge (100 lbs. available N) per acre.

Figure 12

Figure 13

The effect of chromium on the first harvest of bush beans. The two containers on the left contain plants grown in control HOM (high organic matter) soil without tannery sludge or chromium addition; plants on the right were grown in HOM soil amended with the equivalent of 5.8 tons of chromium supplemented sludge per acre. The sludge contained 10 times the initial concentration of chromium.

Figure 13

Figure 14

The effects of tannery sludge and commercial nitrogen fertilizer on growth of bush beans at the second harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 37%.

(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge

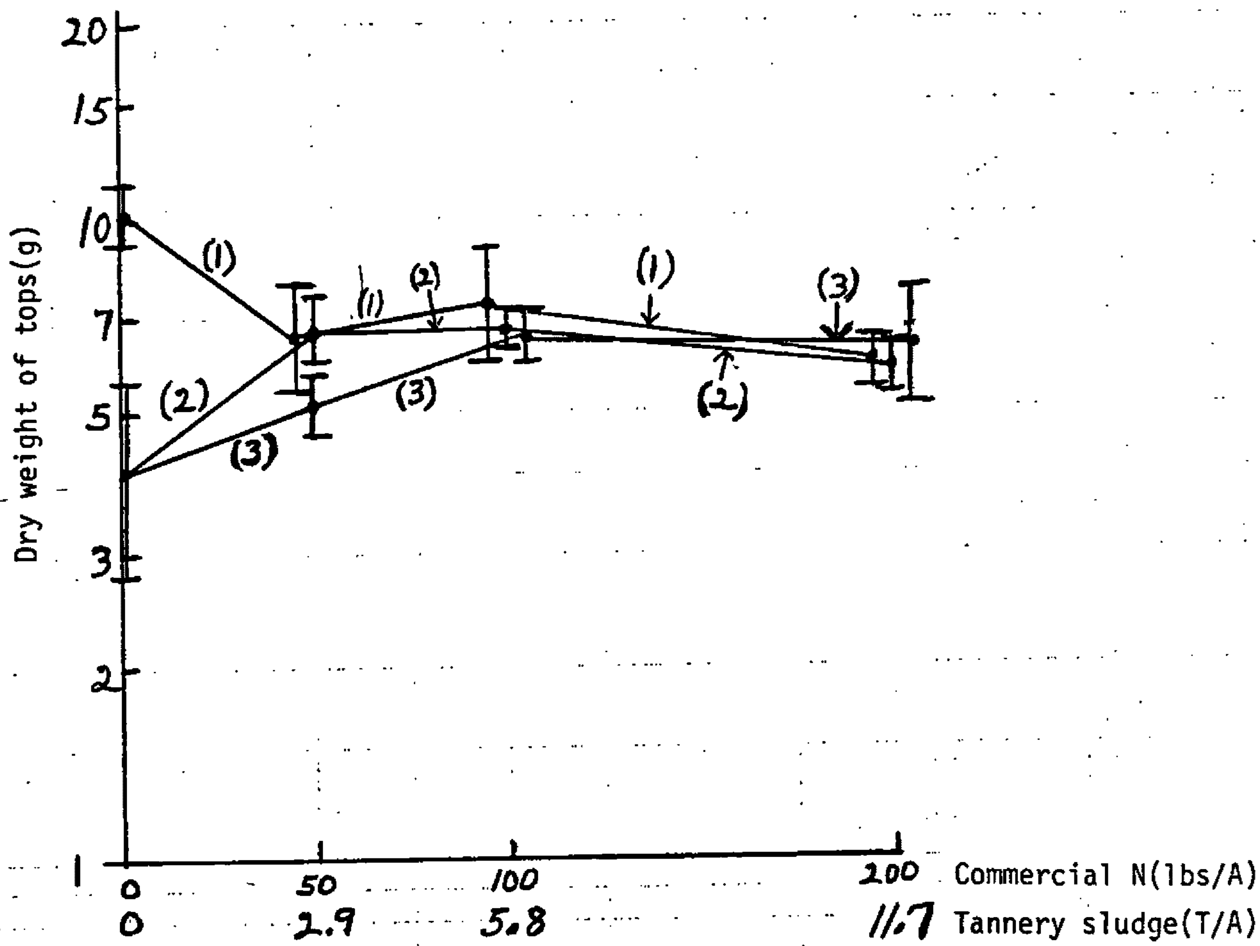

Figure 14

Figure 15

Comparison of the effects of commercial nitrogen fertilizer and tannery sludge on the second harvest of bush beans grown in LOM (low organic matter) soil. The two containers on the left contain plants grown with the equivalent of 100 pounds of commercial nitrogen per acre; those on the right contain plants grown on 5.8 tons of tannery sludge (100 lbs. available N) per acre.

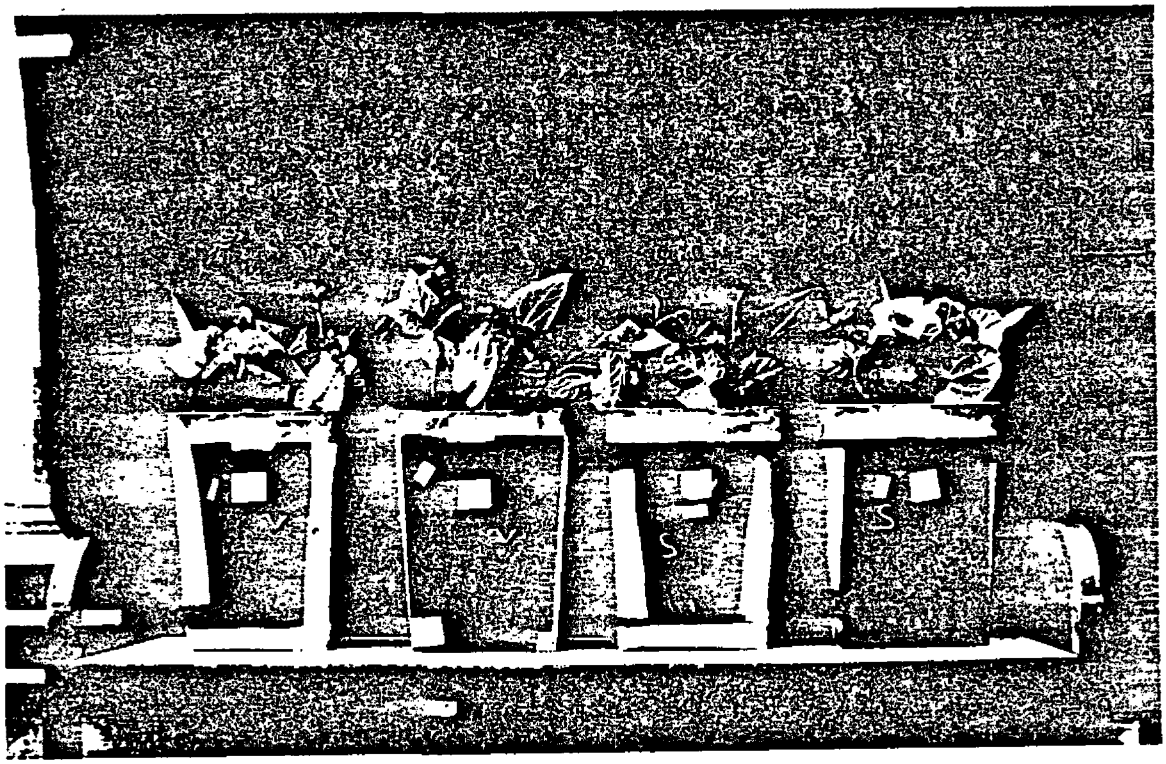

Figure 15

Figure 16

The effects of tannery sludge and commercial nitrogen fertilizer on growth of bush beans at the third harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 52%.

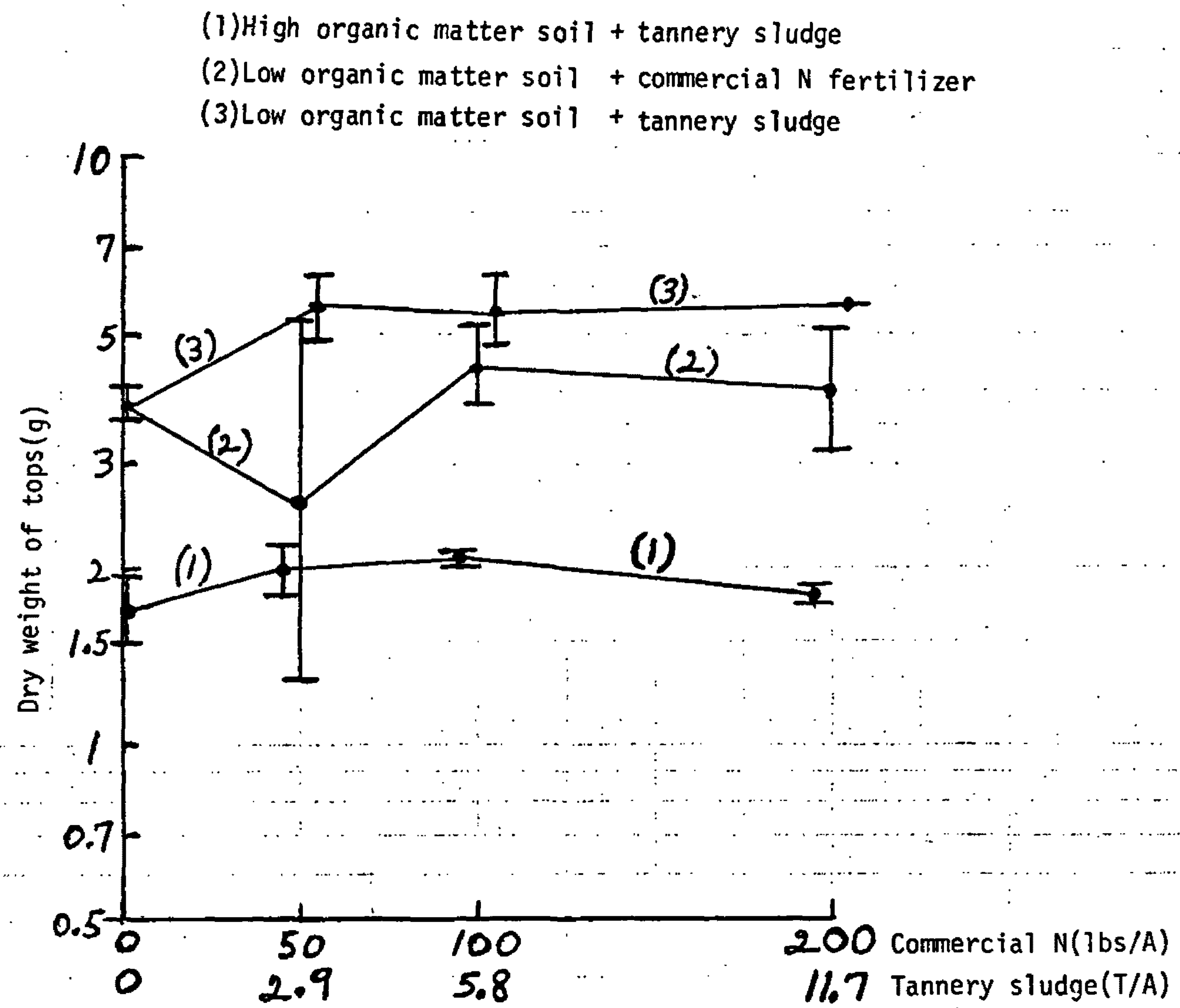
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Dry weight of tops(g)
10
7
5
3
2
1.5
1
0.7
0.5
0
50
100
200
Commercial N(lbs/A)
0
2.9
5.8
11.7
Tannery sludge(T/A)
(1)
(2)
(3)

Figure 16

Figure 17

The effects of tannery sludge and commercial nitrogen fertilizer on nitrogenase activity in the nodules of bush beans at the first harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 277%.

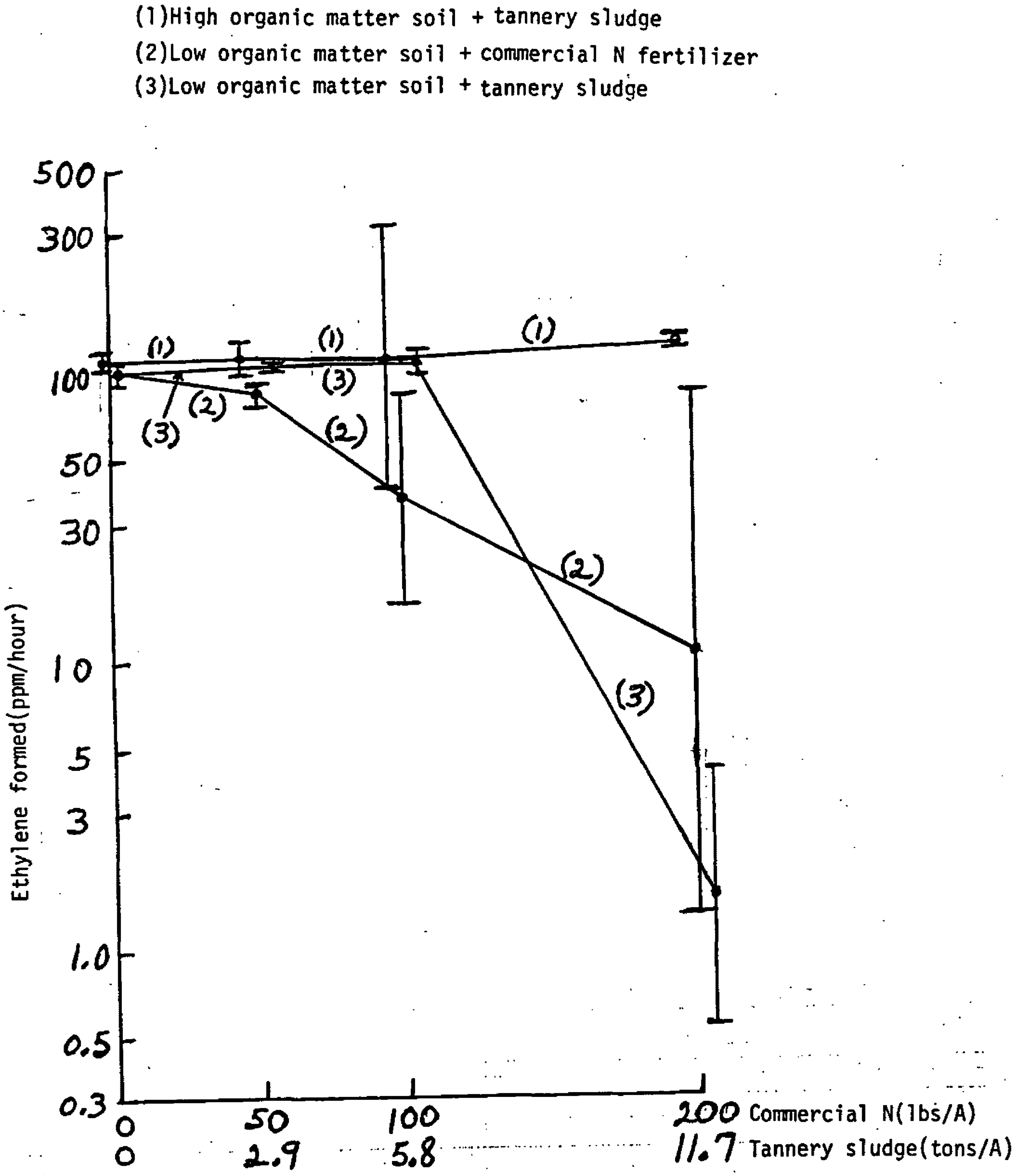
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Ethylene formed(ppm/hour)
500
300
100
50
30
10
5
3
1.0
0.5
0.3
0
50
100
200
Commercial N(lbs/A)
0
2.9
5.8
11.7
Tannery sludge(tons/A)
(1)
(2)
(3)

Figure 17

Figure 18

The effects of tannery sludge and commercial nitrogen fertilizer on nitrogenase activity in the nodules of bush beans at the second harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 503%.

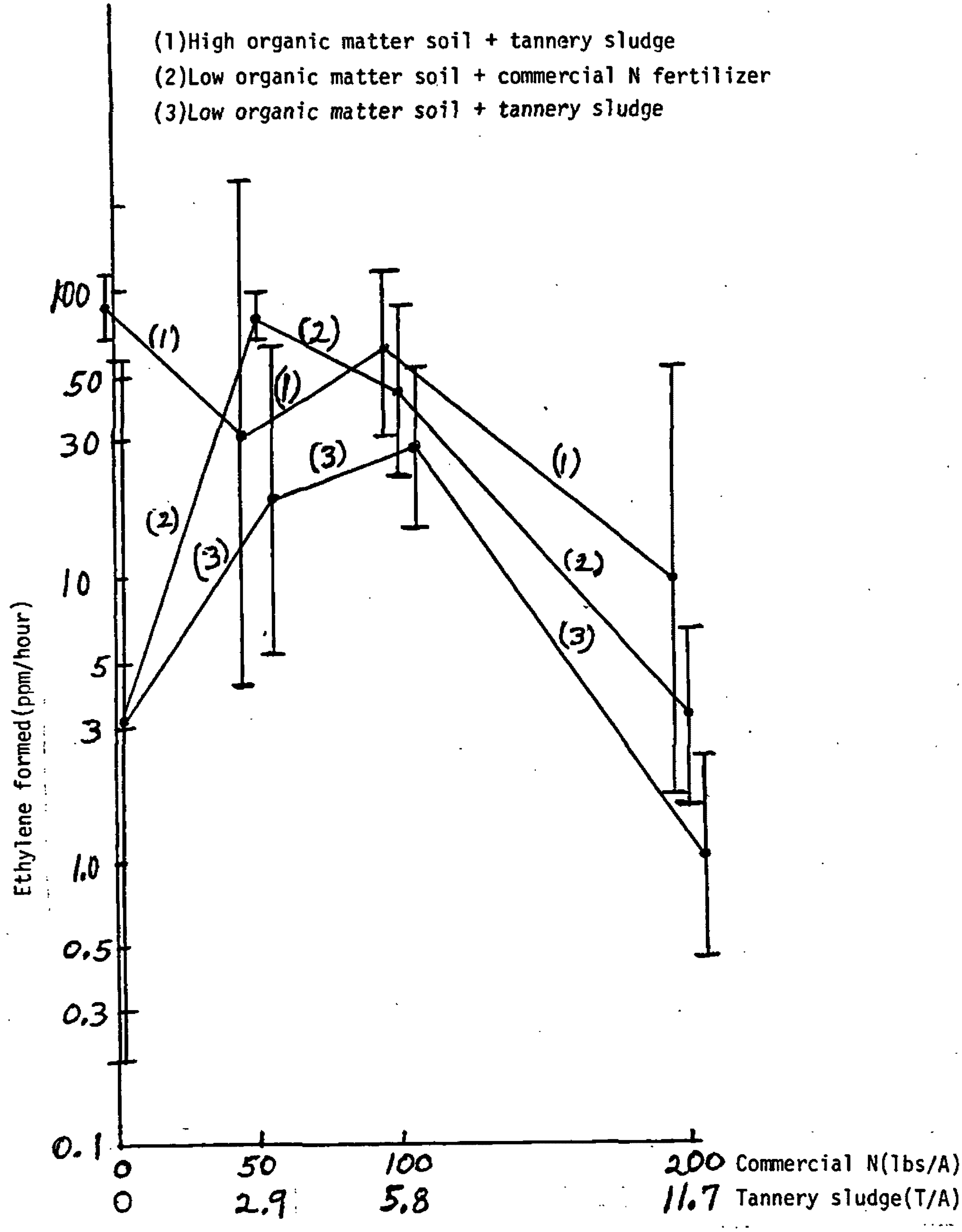
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Ethylene formed(ppm/hour)
100
50
30
10
5
3
1.0
0.5
0.3
0.1
0
50
100
200
Commercial N(lbs/A)
0
2.9
5.8
11.7
Tannery sludge(T/A)

Figure 18

Figure 19

The effects of tannery sludge and commercial nitrogen fertilizer on nitrogenase activity in the nodules of bush beans at the third harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 930%.

(1)High organic matter soil + tannery sludge

(2)Low organic matter soil + commercial N fertilizer

(3)Low organic matter soil + tannery sludge

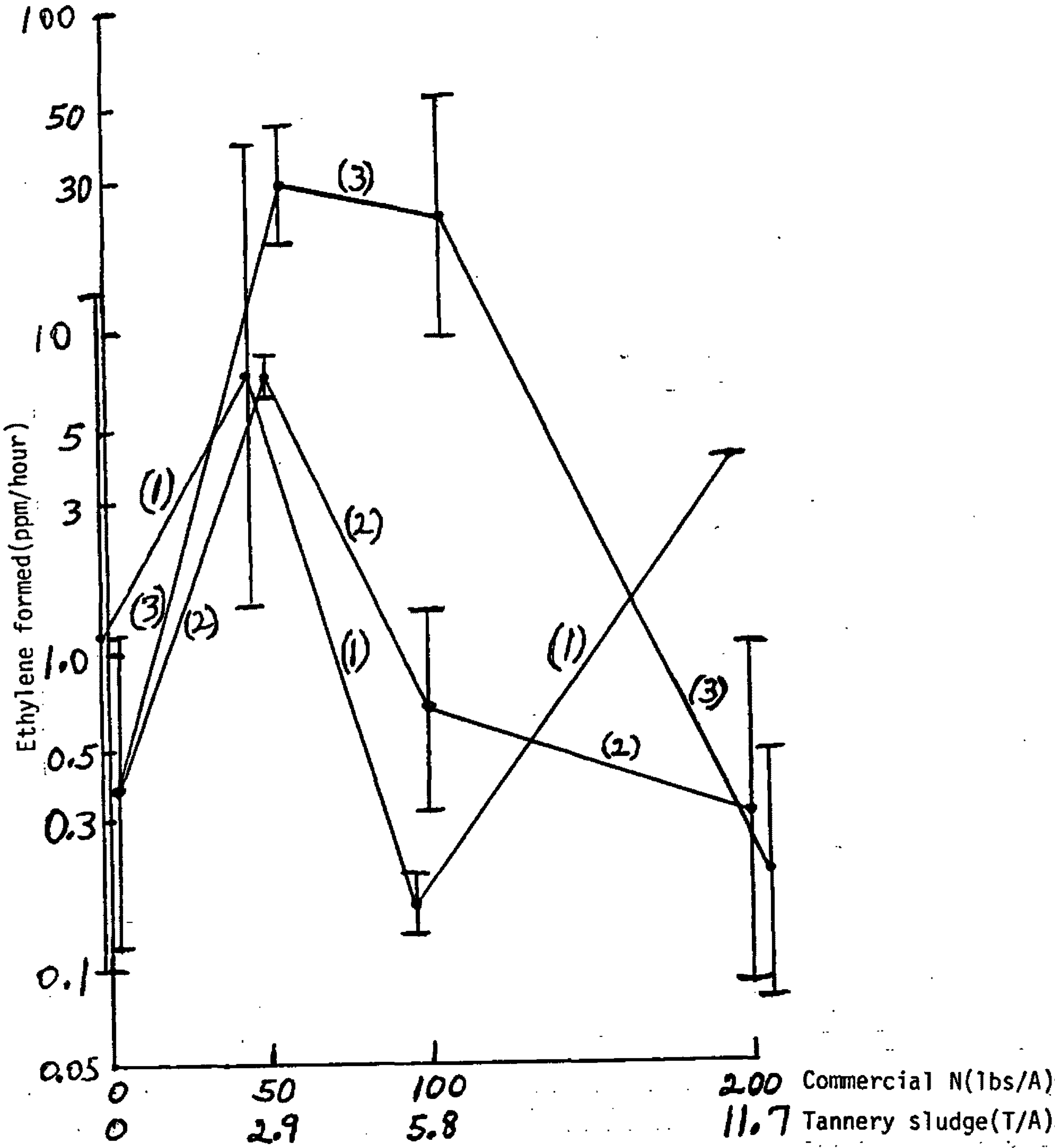

Figure 19

Figure 20

The effects of tannery sludge and commercial nitrogen fertilizer on the growth of corn at the first harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 39%.

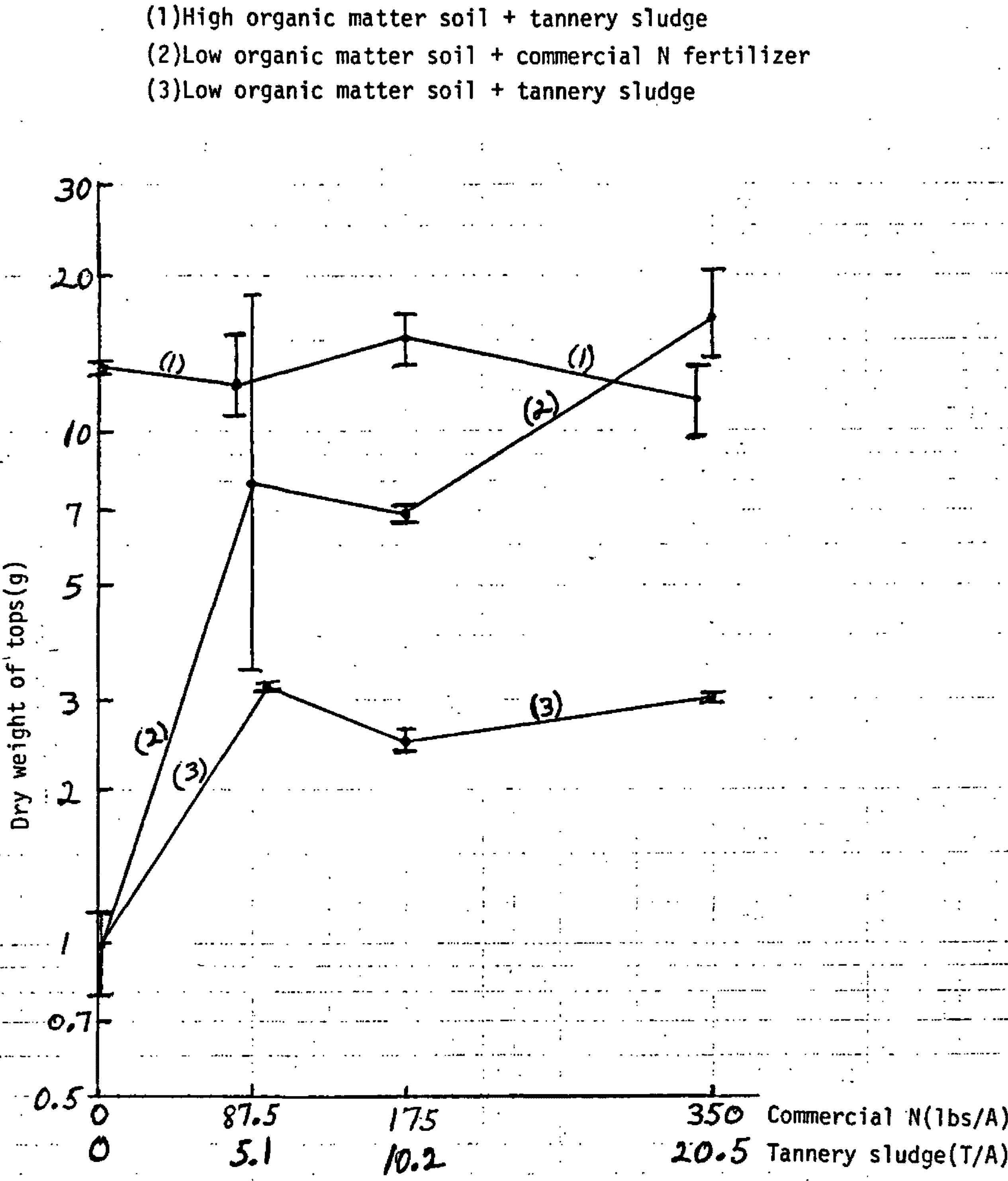
(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge
Dry weight of tops(g)
30
20
10
7
5
3
2
1
0.7
0.5
0
87.5
175
350
Commercial N(lbs/A)
0
5.1
10.2
20.5
Tannery sludge(T/A)
(1)
(2)
(3)

Figure 20

Figure 21

The effect of commercial nitrogen fertilizer on the growth of corn in LOM (low organic matter) soil. The two left containers contain plants grown in control LOM soil without fertilizer and those on the right contain plants grown with 175 pounds of commercial nitrogen fertilizer per acre.

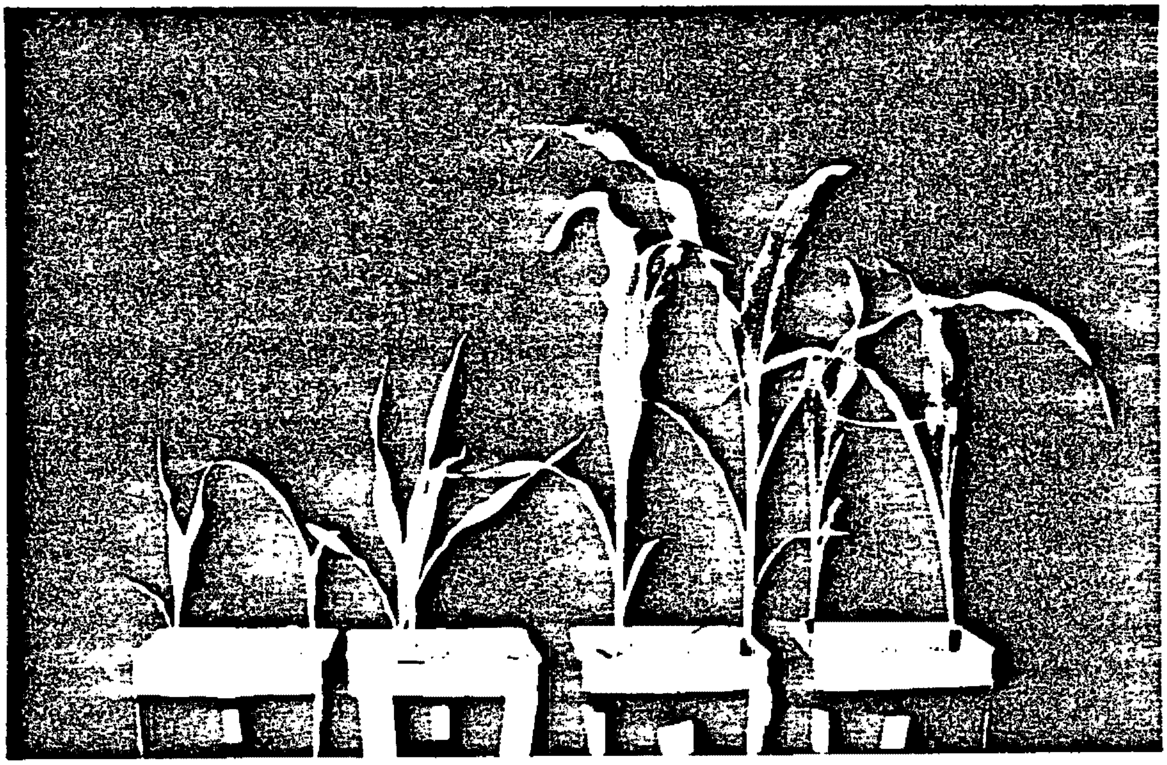

Figure 21

Figure 22

The effect of tannery sludge on the growth of corn in LOM (low organic matter) soil. The two left containers contain plants grown in LOM soil amended with the equivalent of 10.2 tons tannery sludge (175 lbs. available N) per acre; containers on the right contain plants grown in control LOM soil without tannery sludge.

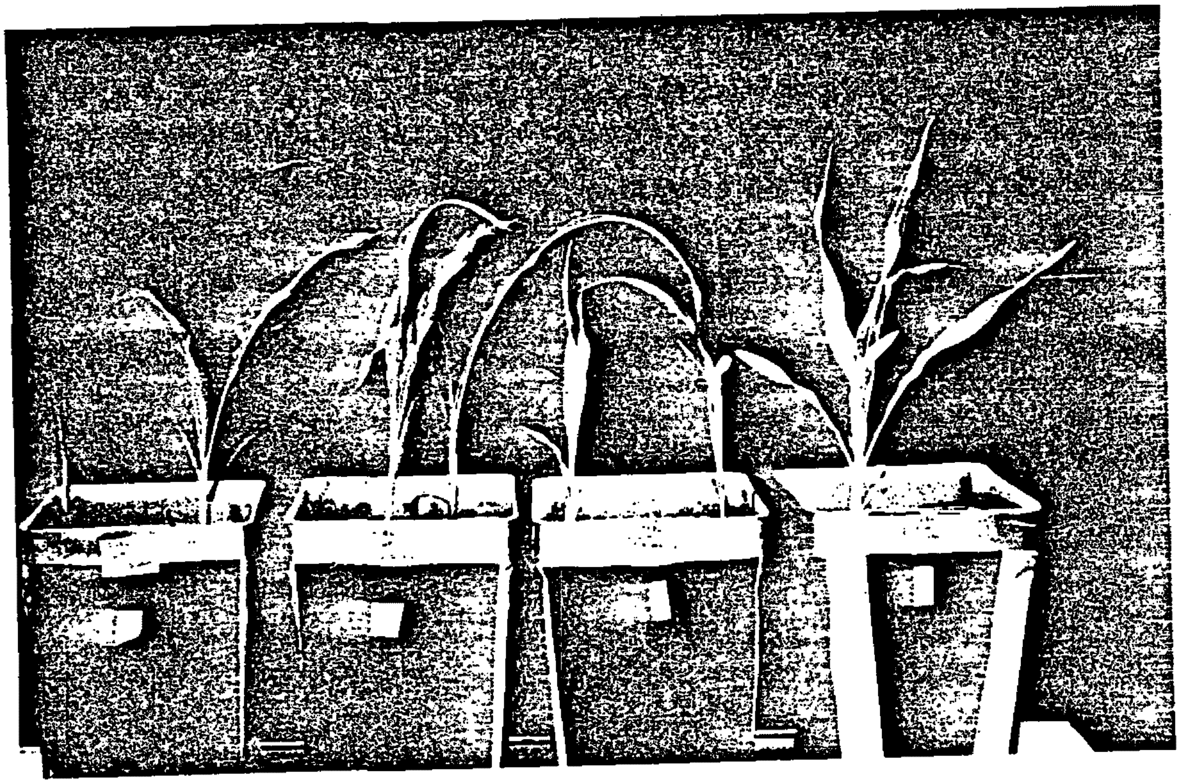

Figure 22

Figure 23

Comparison of the effects of commercial nitrogen fertilizer and tannery sludge on the first havest of corn grown in LOM (low organic matter) soil. The two containers on the left contain plants grown in LOM soil amended with the equivalent of 175 pounds of commercial nitrogen fertilizer per acre; those on the right contain plants grown in LOM soil amended with 10.2 tons tannery sludge (175 lbs. available N) per acre.

Figure 23

Figure 24

The effect of chromium on the growth of corn. The containers on the left contain plants grown in control HOM (high organic matter) soil without (chromium added); plants on the right were grown in HOM soil with 1.47 g chromium per kg dry soil.

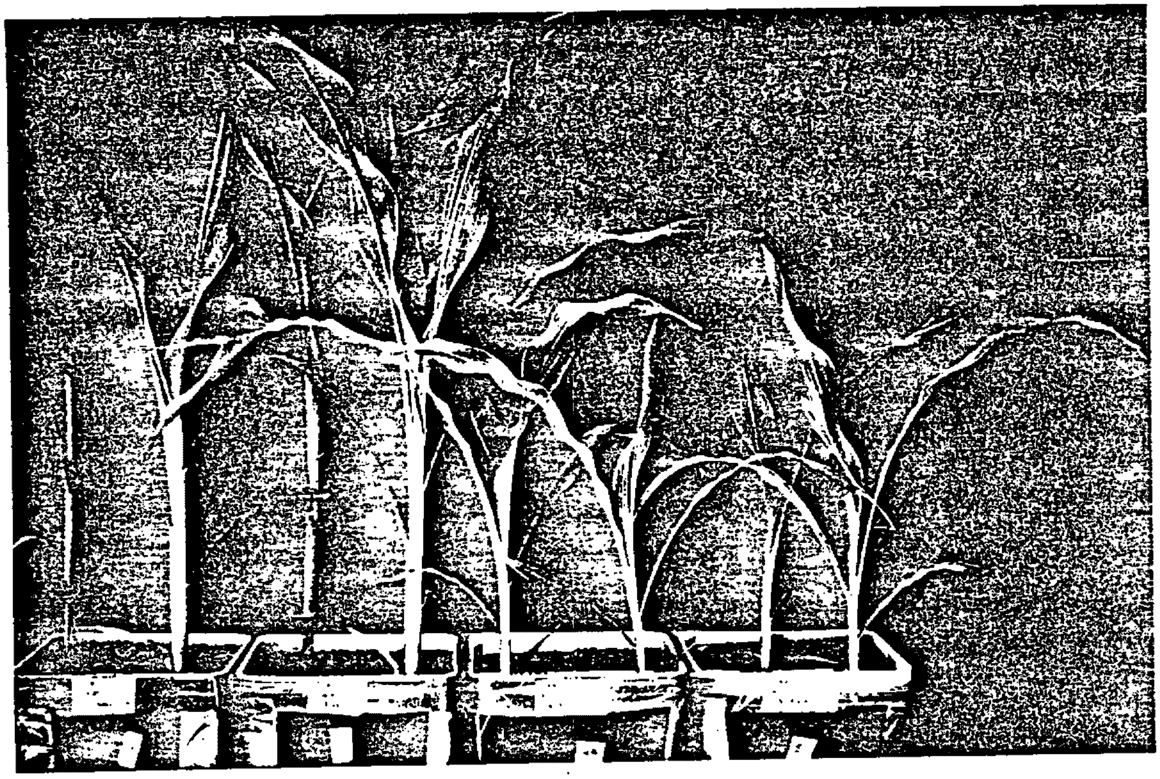

Figure 24

Figure 25

The effects of tannery sludge and commercial nitrogen fertilizer on growth of corn at the second harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 22%.

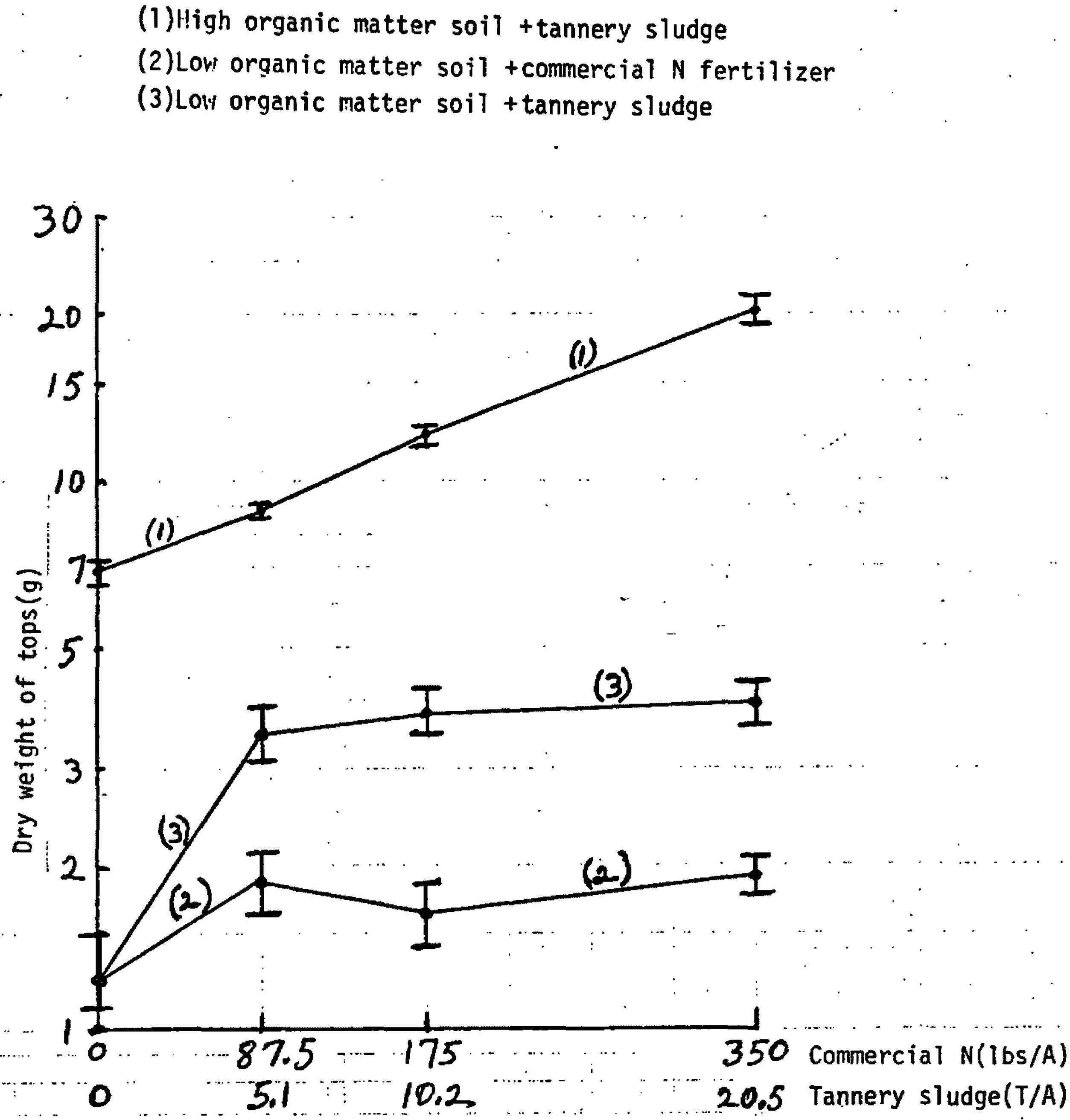
(1)High organic matter soil +tannery sludge
(2)Low organic matter soil +commercial N fertilizer
(3)Low organic matter soil +tannery sludge
Dry weight of tops(g)
30
20
15
10
7
5
3
2
1
(1)
(2)
(3)
0
87.5
175
350
Commercial N(lbs/A)
0
5.1
10.2
20.5
Tannery sludge(T/A)

Figure 25

Figure 26

Comparison of the effects of commercial nitrogen and tannery sludge on the second harvest of corn grown in LOM (low organic matter) soil. The plants on the right were grown with 10.2 tons tannery sludge (175 lbs. available N) per acre and those on the left were grown with 175 pounds of commercial nitrogen per acre.

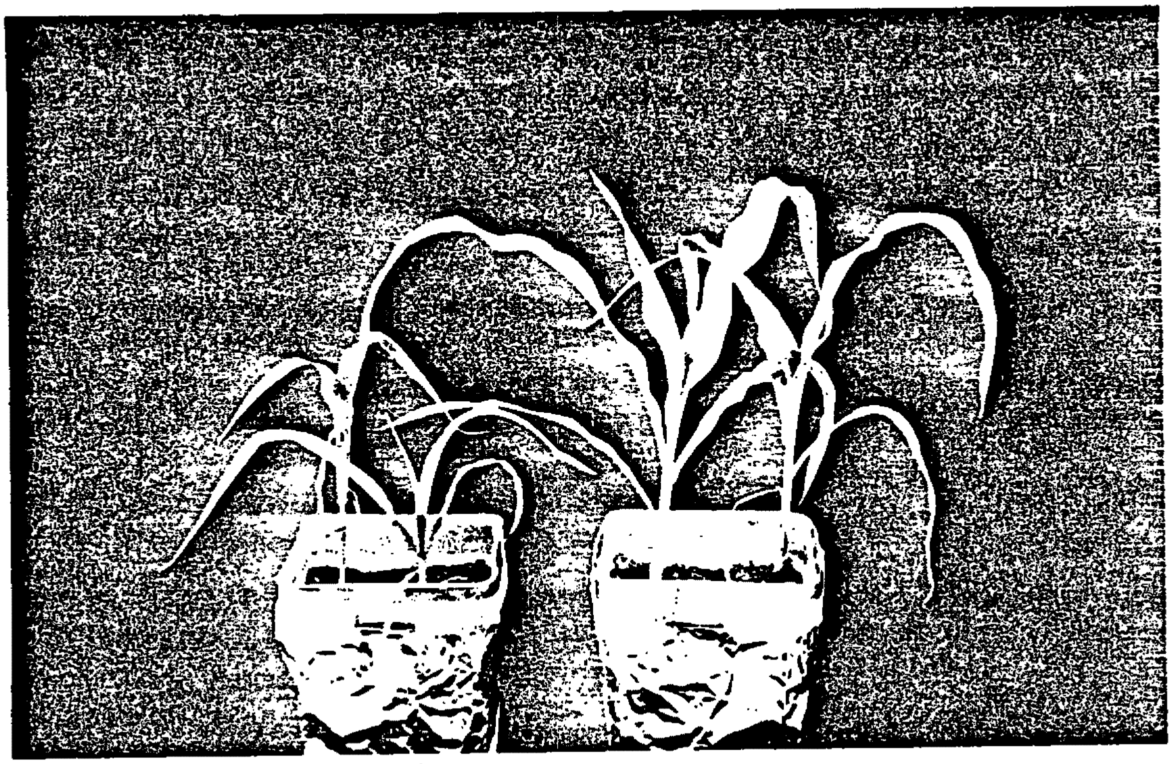

Figure 26

Figure 27

The effects of tannery sludge and commercial nitrogen fertilizer on the growth of corn at the third harvest. Significance of difference between means was determined using the least significant difference (LSD) test (see Methods). LSP 05 = 38%.

(1)High organic matter soil + tannery sludge
(2)Low organic matter soil + commercial N fertilizer
(3)Low organic matter soil + tannery sludge

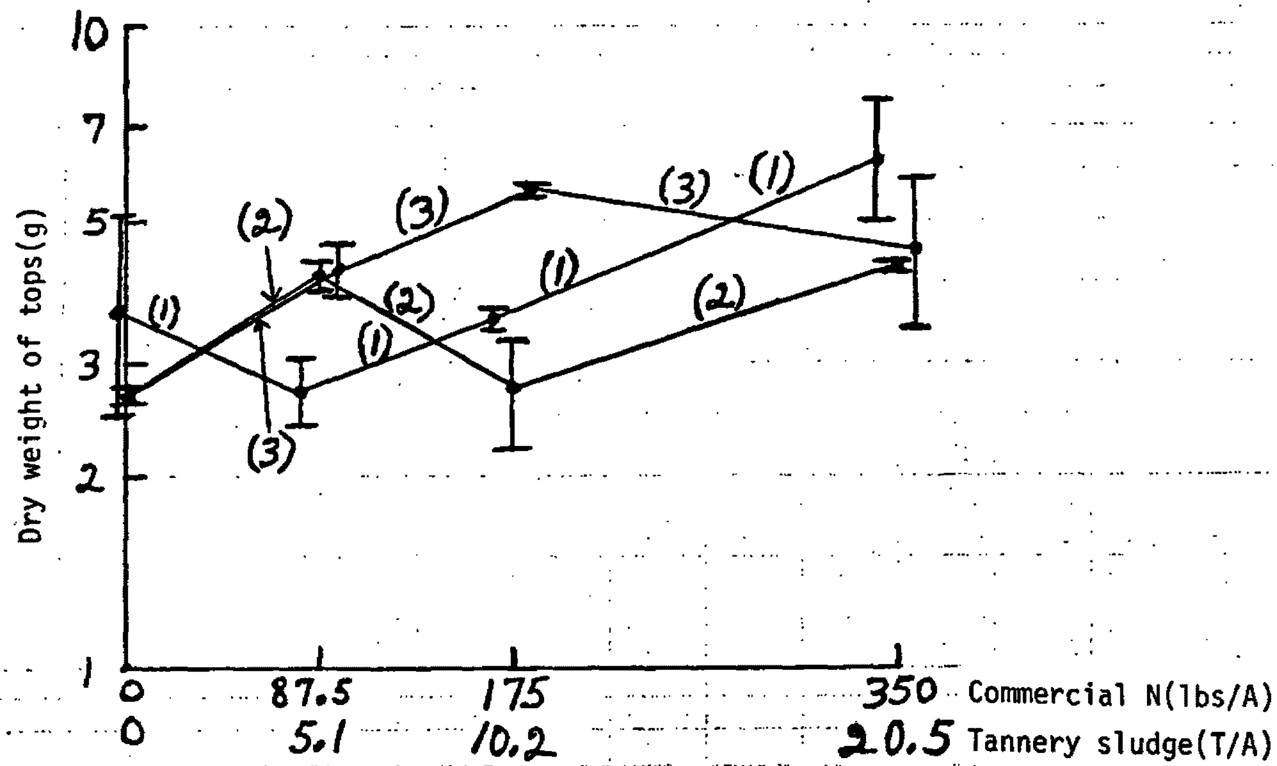

Figure 27

TABLE 1. Preliminary analysis of tannery sludge from the S. B. Foot Tanning Co. in Red Wing, Minnesota, high organic matter (HOM) soil, and low organic matter (LOM) soil. The results are given as mean ± standard deviation.

Constituent		Tannery Sludge	LOM soil	HOM soil
Total N	(g/kg)	28.8 ± 1.1	1.8 ± 0.2	13.1 ± 0.2
Total Cr	(g/kg)	15.9 ± 1.4	0.072 ± 0.016	0.124 ± 0.005
Total Ca	(g/kg)	140.0 ± 10.0	4.56 ± 0.12	17.87 ± 0.26
Soluble Ca	(g/kg)	39 ± 1	1.46 ± 0.01	8.82 ± 0.85
Total P	(g/kg)	1.43 ± 0.05	1.20 ± 0.00	1.98 ± 0.76
Total S	(g/kg)	15.6 ± 1.1	< 0.001	0.001 ± 0.0
Total Mg	(g/kg)	7.49 ± 4.59	0.28 ± 0.01	0.55 ± 0.01
Total Na	(g/kg)	6.45 ± 0.23	0.033 ± 0.006	0.056 ± 0.001
Total Fe	(g/kg)	18.4 ± 0.4	32.67 ± 4.16	19.00 ± 0.30
Total Mn	(g/kg)	1.23 ± 0.05	1.12 ± 0.12	0.26 ± 0.01
Total K	(g/kg)	0.191 ± 0.002	25.30 ± 1.85	7.29 ± 0.26
Organic C	(g/kg)	207 ± 46	71 ± 90.0	381.46 ± 880.0
Inorganic C	(g/kg)	-----	0.040 ± 0.010	0.043 ± 0.006
NH_4	(mg/kg)	56.7 ± 7.0	4.3 ± 0.6	7.3 ± 2.1
NO_2+NO_3	(mg/kg)	< 1.0	< 1.0	46.0 ± 1.7
Total Cd	(mg/kg)	< 3.3	< 5.00	6.00 ± 0.66
Total Cu	(mg/kg)	46.7 ± 11.5	33.63 ± 8.75	48.90 ± 2.70
Total Ni	(mg/kg)	36.0 ± 3.1	76.00 ± 0.70	58.63 ± 1.81
Total Zn	(mg/kg)	182.0 ± 3.5	75.50 ± 1.31	56.57 ± 1.05
Soluble P	(mg/kg)	1.0 ± 0.0	27.33 ± 0.41	212.00 ± 5.20
Total Mo	(mg/kg)	< 80	< 35.5	< 40.0
Lime requirement (pH units)		9.5 ± 0.0	5.7 ± 0.1	5.4 ± 0.0
Electroconductivity (μmho/cm)		-----	144 ± 8	960 ± 28
Cation exchange capacity (meq/100 g		1.2 ± 0.12	2.70 ± 0.36	9.38 ± 0.13
pH		10.2 ± 0.1	5.5 ± 0.0	5.5 ± 0.1
Soluble Mg	(mg/kg)	327 ± 30	276.6 ± 15.3	546.7 ± 5.8
" K	(mg/kg)	122 ± 4	160.3 ± 8.1	486.6 ± 28.9
" SO_4	(mg/kg)	-----	2.2 ± 0.3	7.2 ± 5.1
" Mn	(mg/kg)	-----	50.0 ± 3.5	17.3 ± 1.3
" Mo	(mg/kg)	-----	< 0.9	< 1.5
" B	(mg/kg)	-----	0.19 ± 0.02	0.34 ± 0.06
" Na	(mg/kg)	6050 ± 260	33.7 ± 1.1	55.7 ± 1.1
" Zn	(mg/kg)	-----	1.78 ± 0.20	10.33 ± 1.15
" Cu	(mg/kg)	-----	1.4 ± 0.0	4.2 ± 0.4
" Ni	(mg/kg)	-----	0.6 ± 0.1	1.5 ± 0.2
" Fe	(mg/kg)	-----	199 ± 35	188 ± 115
" Cr	(mg/kg)	-----	< 0.07	< 0.09
" Pb	(mg/kg)	-----	0.57 ± 0.06	0.55 ± 0.15
" Cd	(mg/kg)	-----	< 0.04	0.41 ± 0.04
Total Pb	(mg/kg)	128 ± 11	154 ± 2	148 ± 0
Total B	(mg/kg)	414 ± 20	-----	-----

TABLE 2. Composition of soils for growth of tall fescue.

Soil mixture	Amount of each soil constituent (grams/container)					
	Tannery sludge	Commercial N fertilizer	Lime ($CaCO_3$)	Chromium [as $Cr(OH)SO_4$]	Low organic matter (Amity) soil	High organic matter (Labish) soil
LOM					3119	
LOM + 80 lbs. coml. N/A		0.98			3119	
LOM + 160 lbs. coml. N/A		1.97			3119	
LOM + 320 lbs. coml. N/A		3.94			3119	
LOM + 4.7 tons sludge/A	15.79				3119	
LOM + 9.3 tons sludge/A	31.59				3119	
LOM + 18.7 tons sludge/A	63.18				3119	
HOM						2349
HOM + 4.7 tons sludge/A	11.66					2349
HOM + 9.3 tons sludge/A	23.31					2349
HOM + 18.7 tons sludge/A	46.63					2349
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	31.59			4.27	3119	
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	31.59			47.23	3119	
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	23.31			3.14		2349
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	23.31			34.66		2349
Limed LOM			19.49		3119	
Limed HOM			57.69			2349
Limed LOM + 320 lbs. coml. N/A		3.94	19.49		3119	
Limed LOM + 18.7 tons sludge/A	63.18		19.49		3119	
Limed HOM + 18.7 tons sludge/A	46.63		57.60			2349
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	63.18		19.49	46.48	3119	
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	46.63		57.60	34.30		2349

TABLE 3. Composition of soils for growth of bush bean.

Soil mixture	Amount of each soil constituent (grams/container)					
	Tannery sludge	Commercial N fertilizer	Lime ($CaCO_3$)	Chromium [as $Cr(OH)SO_4$]	Low organic matter (Amity) soil	High organic matter (Labish) soil
LOM					3119	
LOM + 50 lbs. coml. N/A		0.60			3119	
LOM + 100 lbs. coml. N/A		1.21			3119	
LOM + 200 lbs. coml. N/A		2.42			3119	
LOM + 2.9 tons sludge/A	9.85				3119	
LOM + 5.8 tons sludge/A	19.70				3119	
LOM + 11.7 tons sludge/A	39.40				3119	
HOM						2349
HOM + 2.9 tons sludge/A	7.27					2349
HOM + 5.8 tons sludge/A	14.51					2349
HOM + 11.7 tons sludge/A	29.08					2349
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	19.70			2.66	3119	
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	19.70			29.20	3119	
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	14.54			1.97		2349
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	14.54			21.58		2349
Limed LOM			19.49		3119	
Limed HOM			57.69			2349
Limed LOM + 200 lbs. coml. N/A		2.42	19.49		3119	
Limed LOM + 11.7 tons sludge/A	39.40		19.49		3119	
Limed HOM + 11.7 tons sludge/A	29.08		57.60			2349
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	39.40		19.49	28.90	3119	
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	29.08		57.60	21.36		2349

TABLE 4. Composition of soils for growth of corn.

Soil mixture	Amount of each soil constituent (grams/container)					
	Tannery sludge	Commercial N fertilizer	Lime ($CaCO_3$)	Chromium [as $Cr(OH)SO_4$]	Low organic matter (Amity) soil	High organic matter (Labish) soil
LOM					3119	
LOM + 87.5 lbs. coml. N/A		1.06			3119	
LOM + 175 lbs. coml. N/A		2.12			3119	
LOM + 350 lbs. coml. N/A		4.24			3119	
LOM + 5.1 tons sludge/A	17.02				3119	
LOM + 10.1 tons sludge/A	34.03				3119	
LOM + 20.5 tons sludge/A	68.07				3119	
HOM						2349
HOM + 5.1 tons sludge/A	12.79					2349
HOM + 10.2 tons sludge/A	25.57					2349
HOM + 20.5 tons sludge/A	51.14					2349
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	34.03			4.59	3119	
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	34.03			50.59	3119	
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	25.57			3.46		2349
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	25.57			37.92		2349
Limed LOM			19.49		3119	
Limed HOM			57.69			2349
Limed LOM + 350 lbs. coml. N/A		4.24	19.49		3119	
Limed LOM + 20.5 tons sludge/A	68.07		19.49		3119	
Limed HOM + 20.5 tons sludge/A	51.14		57.60			2349
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	68.07		19.49	49.98	3119	
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	51.14		57.60	37.54		2349

TABLE 5. *Analysis of soil mixtures for fescue growth prior to planting. The soils were low (LOM) and high (HOM) in organic matter content.*

Soil	pH	Lime req. (pH units)	Electro-conduc-tivity (μmho/cm)	Cation Exchange capacity (g/kg)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.5	5.7	144	2.70	1.8	71	0.04	1.46	1.20	<0.001	0.07	<0.07	2.2	4.3
LOM + 80 lbs. coml. N/A	---	---	46	-----	1.7	22	----	----	1.06	------	-----	-------	-----	55.0
LOM + 160 lbs. coml. N/A	---	---	86	-----	1.7	21	----	----	1.08	------	-----	-------	-----	77.5
LOM + 320 lbs. coml. N/A	---	---	132	-----	2.2	21	----	----	1.28	------	-----	-------	-----	175.0
LOM + 4.7 tons sludge/A	5.9	5.9	485	4.05	2.2	24	0.24	2.31	1.20	0.23	0.17	<0.1	29.0	3.1
LOM + 9.3 tons sludge/A	6.2	6.0	150	3.95	2.4	24	0.48	2.91	1.09	0.40	0.27	<0.1	55.5	3.0
LOM + 18.7 tons sludge/A	6.9	6.3	295	3.90	2.6	22	1.18	3.37	1.02	0.20	0.45	<0.1	108.5	3.6
HOM	5.5	5.4	960	9.38	12.1	381	0.04	8.82	1.98	0.001	0.12	<0.09	7.2	7.3
HOM + 4.7 tons sludge/A	6.1	5.5	213		15.3	216	0.28	3.59	2.00	1.55	0.26	<0.1	74.0	5.4
HOM + 9.3 tons sludge/A	6.2	5.7	298	13.5	15.8	213	0.55	3.65	2.10	1.70	0.46	<0.1	79.5	7.8
HOM + 18.7 tons sludge/A	6.6	6.0	393		15.8	213	1.16	3.61	1.99	1.85	0.68	<0.1	-----	5.0
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	1.60	0.95	-----	----
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	19.50	2050	-----	----
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	3.10	0.93	-----	----
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	28.00	16.0	-----	----
Limed LOM	6.7	6.7	27	3.73	1.5	26	0.11	3.65	1.03	0.23		-------	-----	4.0
Limed HOM	7.2	6.4	1,650	-----	11.6	102	1.33	3.19	1.84	------	0.08	-------	-----	8.1
Limed LOM + 320 lbs. coml. N/A	6.8	6.7	1,215	-----	----	62	----	----	----	------	-----	-------	-----	----
Limed LOM + 18.7 tons sludge/A	7.2	6.8	2,750	-----	2.0	23	1.16	3.28	0.95	0.43	0.46	0.1	93.0	9.8
Limed HOM + 18.7 tons sludge/A	7.2	6.9	2,825	-----	11.2	205	2.77	3.63	1.79	1.45	0.43	<0.1	155.0	37.0
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	14.50	44.5	-----	----
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	---	---	-----	-----	----	---	----	----	----	------	24.50	1.55	-----	----

TABLE 5. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.6	<1.0	27.3	276	160	34	199	0.6	1.4	1.8	50	<0.04	<0.9	0.19
LOM + 80 lbs. coml. N/A	----	1.1	16.0	---	---	---	---	-----	----	----	--	-----	----	-----
LOM + 160 lbs. coml. N/A	----	0.6	13.5	---	---	---	---	-----	----	----	--	-----	----	-----
LOM + 320 lbs. coml. N/A	----	2.0	34.0	---	---	---	---	-----	----	----	--	-----	----	-----
LOM + 4.7 tons sludge/A	1.1	<0.2	11.0		213	82	138	1.0	1.5	1.5	33	<0.04	<0.9	<0.10
LOM + 9.3 tons sludge/A	<0.8	0.4	10.2		159	110	124	0.7	1.4	1.6	31	<0.04	<0.9	<0.10
LOM + 18.7 tons sludge/A	<0.8	0.6	9.0		153	162	125	0.7	1.7	2.0	35	<0.04	<0.9	<0.10
HOM	1.5	46.0	212.0	546	486	56	188	0.5	4.2	10.3	17	0.41	<1.5	0.34
HOM + 4.7 tons sludge/A	1.0	65.5	86.0	---	565	121	340	0.7	4.2	12.0	11	0.46	<0.9	0.22
HOM + 9.3 tons sludge/A	1.4	53.0	70.0	---	580	156	380	0.6	5.1	12.0	10	0.58	<0.9	0.23
HOM + 18.7 tons sludge/A	1.2	7.5	59.0	---	340	210	352	0.8	3.8	13.0	2	0.61	<0.9	
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----
Limed LOM	<0.8	3.7	10.5	299	186	44	111	0.4	1.3	0.7	9	0.06	<0.9	<0.10
Limed HOM	1.2	66.0	50.2	670	435	73	190	0.3	2.1	10.0	9	0.42	<0.9	<0.10
Limed LOM + 320 lbs. coml. N/A	----	-----	-----		---	---	---	-----	----	----	--	-----	-----	-----
Limed LOM + 18.7 tons sludge/A	<0.8	<0.37	6.0	350	191	161	76	0.4	1.4	1.5	19	<0.04	<0.9	<0.10
Limed HOM + 18.7 tons sludge/A	0.8	11.7	29.5	650	408	197	123	0.3	1.1	7.0	4	0.26	<0.9	<0.10
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	----	-----	-----	---	---	---	---	-----	----	----	--	-----	-----	-----

TABLE 6. Analysis of soil mixtures for fescue growth 23 weeks after seed planting. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (µmho/cm)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.4	5.9	5250	1.9	22	0.07	1.5	0.97	<0.3	<0.05	<4	<0.8
LOM + 80 lbs. coml. N/A	---	---	----	1.9	---	-----	----	1.01	----	-----	---	----
LOM + 160 lbs. coml. N/A	---	---	----	1.9	---	-----	----	0.98	----	-----	---	----
LOM + 320 lbs. coml. N/A	---	---	----	1.9	---	-----	----	1.00	----	-----	---	----
LOM + 4.7 tons sludge/A	5.3	6.2	3050	2.0	22	<0.05	2.2	0.98	0.5	<0.07	215	<0.8
LOM + 9.3 tons sludge/A	5.9	6.6	5250	2.1	24	0.05	3.1	0.97	0.6	<0.05	290	<0.8
LOM + 18.7 tons sludge/A	6.9	7.0	2450	2.3	23	0.12	4.2	0.94	0.7	<0.05	225	1.0
HOM	5.6	5.3	303	12.0	195	<0.02	9.5	1.80	1.2	0.12	<4	2.6
HOM + 4.7 tons sludge/A	5.9	5.6	378	12.5	225	<0.03	10.5	1.95	1.5	<0.05	21	2.8
HOM + 9.3 tons sludge/A	6.2	5.7	345	14.5	223	0.09	11.0	2.05	1.6	<0.06	16	2.7
HOM + 18.7 tons sludge/A	6.6	6.1	790	4.0	226	0.16	12.5	2.00	1.7	<0.07	66	1.7
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	0.45	---	----
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	8720.0	---	----
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	0.35	---	----
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	12.3	---	----
Limed LOM	7.0	6.9	330	1.9	21	0.10	3.2	0.91	<0.3	<0.05	<10	<0.8
Limed HOM	7.1	6.5	----	13.2	212	2.06	1.4	1.87		<0.05	<11	2.8
Limed LOM + 320 lbs. coml. N/A	---	---	----	1.9	---	-----	----	0.94	----	-----	---	<0.8
Limed LOM + 18.7 tons sludge/A	7.4	6.9	----	2.3	24	1.21	10.4	0.95	1.0	<0.05	163	2.1
Limed HOM + 18.7 tons sludge/A	7.4	6.9	1205	12.5	204	3.34	9.9	1.90	1.0	0.09	73	2.1
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	3215.0	---	----
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	---	---	----	----	---	-----	----	----	----	0.45	---	----

TABLE 6. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.87	<2.0	21	360	152	64	184	0.88	2.42	21.7	35.9	0.06	<0.22	---
LOM + 80 lbs. coml. N/A	----	<2.0	---	---	---	---	---	----	----	----	----	-----	-----	---
LOM + 160 lbs. coml. N/A	----	<2.0	---	---	---	---	---	----	----	----	----	-----	-----	---
LOM + 320 lbs. coml. N/A	----	<2.0	---	---	---	---	---	----	----	----	----	-----	-----	---
LOM + 4.7 tons sludge/A	1.19	<2.0	19	430	127	222	184	0.88	2.57	20.0	41.3	0.04	<0.18	---
LOM + 9.3 tons sludge/A	0.43	<2.0	18	430	120	200	157	0.82	2.01	16.5	39.6	0.05	<0.18	---
LOM + 18.7 tons sludge/A	0.35	<2.0	16	330	117	157	108	0.70	2.17	16.5	30.5	0.04	<0.18	---
HOM	1.37	2.6	180	730	310	72	482	<0.10	1.60	62.8	2.5	0.48	<0.18	---
HOM + 4.7 tons sludge/A	1.24	<2.0	145	750	270	107	481	<0.10	1.52	69.5	2.2	0.60	<0.18	---
HOM + 9.3 tons sludge/A	1.79	<2.0	115	790	240	92	488	<0.10	1.56	80.8	2.9	0.62	<0.18	---
HOM + 18.7 tons sludge/A	1.94	<2.0	81	800	212	130	499	0.17	3.96	0.1	10.2	0.57	<0.20	---
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---
Limed LOM	0.37	<2.0	19	310	130	62	98	0.56	1.60	17.1	17.2	<0.03	<0.18	---
Limed HOM	2.01	<2.0	75	730	250	50	461	0.30	3.04	0.1	7.4	0.54	<0.18	---
Limed LOM + 320 lbs. coml. N/A	----	<2.0	---	---	---	---	---	-----	----	----	----	-----	-----	---
Limed LOM + 18.7 tons sludge/A	0.56	<2.0	18	330	117	167	104	0.65	3.31	28.1	57.2	0.04	<0.18	---
Limed HOM + 18.7 tons sludge/A	1.96	<2.0	51	720	250	125	---	0.44	2.91	0.1	22.9	0.49	<0.18	---
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	----	----	---	---	---	---	---	-----	----	----	----	-----	-----	---

TABLE 7. Final analysis of soil mixtures for fescue growth. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.6	6.0	1425	2.0	21	0.03	1.48	1.1	<0.20	0.03	0.1	<15	2.4
LOM + 80 lbs. coml. N/A	5.5	5.9	195	2.0	21	0.06	1.48	1.0	<0.20	0.05	<0.2	<17	<2.0
LOM + 160 lbs. coml. N/A	5.3	5.9	300	1.9	21	0.05	1.46	1.1	<0.20	0.03	<0.2	<41	<2.0
LOM + 320 lbs. coml. N/A	5.2	5.9	525	2.0	22	0.08	1.37	1.1	<0.20	0.05	<0.2	<36	2.0
LOM + 4.7 tons sludge/A	5.7	6.2	583	2.1	22	0.05	2.02	1.1	<0.20	0.14	<0.2	<52	2.1
LOM + 9.3 tons sludge/A	6.2	6.0	1285	2.2	22	0.07	2.80	1.0	0.30	0.21	<0.2	140	2.1
LOM + 18.7 tons sludge/A	6.9	7.0	1885	2.1	23	0.07	3.90	0.9	0.40	0.45	0.2	295	3.1
HOM	6.3	6.1	535	13.0	181		9.55	1.9	1.40	0.08	<0.2	<21	5.1
HOM + 4.7 tons sludge/A	5.8	5.5	568	14.0	182	0.07	9.60	2.0	1.45	0.20	<0.2	74	4.2
HOM + 9.3 tons sludge/A	6.1	6.2	590	13.5	174	0.06	10.40	1.8	1.53	0.30	<0.2	56	3.9
HOM + 18.7 tons sludge/A	6.5	6.2	700	13.5	189	0.09	11.50	1.8	1.75	0.55	<0.2	95	4.2
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	5.0	6.2	8750	2.0	28	0.06	2.90	0.9	1.75	2.00	0.6		4.3
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	3.8	3.9	72,500	2.0	21	0.06	2.60	0.9	13.45	14.00	2400.0	22,500	8.7
HOM + 9/3 tons sludge/A + 1.34 g Cr/kg dry soil	5.6	5.6	7,250	13.5	197	0.07	9.90	1.9	3.90	2.20	0.9	3,550	4.4
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	3.8	5.3	4,300	11.0	157	0.06	11.50	1.7	19.50	18.50	1.6	15,000	34.0
Limed LOM	7.0	7.0	294	1.8	24	0.08	3.20	0.9	0.20	0.03	0.3	<92	2.3
Limed HOM	6.7	6.0	455	12.0	179		12.00	1.8	1.40	0.09	<0.2	<22	4.8
Limed LOM + 320 lbs. coml. N/A	6.7	6.7	1,015	1.7	21	0.06	3.20	1.0	0.45	0.03	<0.2	320	2.1
Limed LOM + 18.7 tons sludge/A	7.5	7.2	1,835	2.1	22	0.09	5.80	0.9	0.55	0.35	<0.2	235	2.9
Limed HOM + 18.7 tons sludge/A	7.5	6.9	1,260	12.5	180		14.00	1.8	1.75	0.49	<0.2	<180	3.9
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	3.6	5.3	48,250	2.1	22	0.05	5.70	0.9	14.10	15.00	6.9	13,000	3.3
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	6.5	6.6	27,850	11.0	169	0.10	16.50	1.7	18.25	19.00	0.7	8,100	4.2

TABLE 7. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.7	<4.0	21	300	145	47	195	3.9	1.6	1.7	55	0.1	<1	<0.10
LOM + 80 lbs. coml. N/A	0.7	<4.0	13	320	155	42	144	2.0	1.6	2.1	54	0.1	<1	<0.10
LOM + 160 lbs. coml. N/A	0.7	<4.0	9	300	145	42	166	2.2	1.6	2.6	49	0.1	<1	<0.10
LOM + 320 lbs. coml. N/A	0.6	<4.0	16	300	174	47	174	1.9	1.6	3.4	58	0.1	<1	<0.10
LOM + 4.7 tons sludge/A	0.4	<4.0	<6	330	134	79	139	2.4	1.8	2.0	38	0.1	<1	<0.10
LOM + 9.3 tons sludge/A	0.6	<4.0	<4	320	110	95	96	3.0	1.4	1.2	17	0.1	<1	<0.10
LOM + 18.7 tons sludge/A	<0.3	<4.0	<4	250	92	128	65	2.3	1.4	1.6	13	<0.1	<1	<0.10
HOM	1.7	<4.0	78	590	255	66	390	1.2	4.2	9.7	6	0.5	<1	0.13
HOM + 4.7 tons sludge/A	1.5	<4.0	115	680	240	99	550	1.8	3.2	12.4	6	0.5	<1	0.22
HOM + 9.3 tons sludge/A	2.3	<4.0	86	640	193	106	400	0.9	3.3	12.6	6	0.5	<1	—
HOM + 18.7 tons sludge/A	1.7	<4.0	33	635	163	123	420	2.4	3.3	12.7	6	0.5	<1	0.14
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	0.5	—	<4	320	127	870	83	1.0	1.2	1.5	155	<0.1	<1	0.13
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	1.7	<4.0	5	360	195	9,700	117	1.5	0.3	1.0	280	<0.1	<1	0.33
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	1.7	<4.0	60	660	330	1,350	360	0.4	3.0	10.4	11	0.5	<1	0.23
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	2.0	6.5	<7	720	520	11,750	115	0.5	1.0	10.7	60	0.2	<1	0.49
Limed LOM	0.2	<4.0	<4	260	122	35	70	3.0	1.4	3.8	12	0.1	<1	0.10
Limed HOM	1.9	<4.0	83	640	250	63	360	0.7	3.2	10.6	7	0.6	<1	0.11
Limed LOM + 320 lbs. coml. N/A	0.3	<4.0	11	280	132	35	91	2.1	1.4	1.8	22	0.1	<1	0.10
Limed LOM + 18.7 tons sludge/A	0.5	<4.0	<4	240	98	138	84	1.9	1.9	3.2	29	0.1	<1	0.10
Limed HOM + 18.7 tons sludge/A	1.7	<4.0	15	560	124	132	310	0.4	2.8	10.0	15	0.4	<1	0.10
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	0.9	<4.0	<4	360	195	8,600	44	0.1	<0.5	0.6	26	<0.1	<1	0.23
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	1.9	<4.0	<4	750	320	12,000	141	0.7	1.6	4.8	10	0.2	<1	0.11

TABLE 8. Analysis of soil mixtures for bush bean growth prior to planting. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	Cation exchange capacity (g/kg)	Total N (g/kg)	Inorg. C (g/kg)	Org. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.5	5.7	144	2.70	1.8	0.04	71	1.46	1.20	<0.001	0.072	<0.07	2.2	4.3
LOM + 50 lbs. coml. N/A	---	---	33	-----	1.7	----	21	----	1.10	------	-----	-----	-----	28.5
LOM + 100 lbs. coml. N/A	---	---	52	-----	1.6	----	20	----	1.05	------	-----	-----	-----	75.5
LOM + 200 lbs. coml. N/A	---	---	124	-----	1.8	----	18	----	1.15	------	-----	-----	-----	102.5
LOM + 2.9 tons sludge/A	5.7	5.7	-----	3.72	1.6	0.05	19	2.15	1.01	0.16	0.14	<0.10	-----	2.4
LOM + 5.8 tons sludge/A	5.8	6.0	104	3.85	1.7	0.27	19	2.54	1.02	0.11	0.16	<0.10	-----	2.6
LOM + 11.7 tons sludge/A	6.1	6.1	196	3.75	1.9	----	21	3.29	1.03	0.42	0.32	<0.10	69.0	3.9
HOM	5.5	5.4	960	9.38	13.1	0.04	381	8.82	1.98	0.001	0.12	1.50	7.2	7.3
HOM + 2.9 tons sludge/A	5.9	5.4	158	11.50	12.8	0.10	221	3.61	1.98	1.60	0.20	<0.10	—	5.0
HOM + 5.8 tons sludge/A	6.1	5.5	229	15.00	12.5	0.28	221	3.76	1.98	1.70	0.28	<0.10	81.0	8.9
HOM + 11.7 tons sludge/A	6.2	5.7	285	13.50	12.9	0.42	283	3.53	1.95	1.75	0.46	<0.10	91.5	7.9
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	1.00	0.70	—	-----
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	11.00	465.00	-----	-----
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	1.25	1.45	-----	-----
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	12.00	5.85	-----	-----
Limed LOM	6.9	6.7	270	3.72	1.5	0.11	26	3.61	1.03	0.23	<0.06	<0.10	3.6	3.7
Limed HOM	7.2	6.4	1,165	-----	11.5		165	3.69	1.84	1.45	0.08	<0.10	21.0	7.6
Limed LOM + 200 lbs. coml. N/A	6.9	6.7	1,115	-----		----	24	----	----	------	-----	------	-----	95.3
Limed LOM + 11.7 tons sludge/A	7.0	6.5	1,070	3.90	1.8	0.77	22	3.41	0.97	0.36	0.23	0.10	74.0	3.6
Limed HOM + 11.7 tons sludge/A	7.0	6.8	1,940	-----	11.7	2.44	212	3.59	1.82	1.65	0.39	<0.10	145.0	8.0
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	9.50	4.90	------	-----
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	---	---	-----	-----	----	----	---	----	-----	------	14.00	2.19	------	-----

TABLE 8. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.6	1.0	27	277	160	34	199	0.57	1.4	1.8	50	<0.04	<0.9	0.19
LOM + 50 lbs. coml. N/A	----	2.5	13	---	---	---	---	----	---	----	----	-----	----	-----
LOM + 100 lbs. coml. N/A	----	1.3	11	---	---	---	---	----	---	----	----	-----	----	-----
LOM + 200 lbs. coml. N/A	----	2.5	15	---	---	---	---	----	---	----	----	-----	----	-----
LOM + 2.9 tons sludge/A	<0.7	<0.2	10	---	207	67	157	0.85	1.3	1.4	33	<0.04	<0.9	—
LOM + 5.8 tons sludge/A	<0.8	<0.5	11	340	—	93	144	0.65	1.3	1.7	—	<0.04	<0.9	<0.10
LOM + 11.7 tons sludge/A	<0.8	0.6	9	390	—	128	155	0.90	—	1.8	35	<0.04	<0.9	<0.10
HOM	1.2	46.0	212	547	487	56	188	0.55	4.2	10.3	17	0.41	<1.5	0.34
HOM + 2.9 tons sludge/A	<0.8	61.5	99	730	565	109	359	0.60	3.7	10.0	10	<0.50	<0.9	-----
HOM + 5.8 tons sludge/A	<0.9	61.0	82	760	620	139	360	0.50	3.7	12.0	10	0.50	<0.9	0.21
HOM + 11.7 tons sludge/A	1.6	18.2	74	370	567	184	380	1.20	4.0	11.5	14	0.48	<0.9	0.16
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----
HOM + 5/8 tons sludge/A + 0.84 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----
Limed LOM	<0.8	3.7	10	299	186	44	111	0.45	1.3	0.8	9	—	<0.9	<0.10
Limed HOM	1.2	66.0	50	670	435	73	—	0.35	2.1	10.0	2	0.47	<0.9	<0.10
Limed LOM + 200 lbs. coml. N/A	----	-----	17	—	—	—	190	—	—	—	—	—	—	—
Limed LOM + 11.7 tons sludge/A	<0.8	0.4	7	335	184	122	82	0.45	1.3	1.7	1.7		<0.9	<0.10
Limed HOM + 11.7 tons sludge/A	1.6	29.5	48	745	—	—	285	0.45	3.3		11	0.42	<0.9	<0.10
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	----	-----	---	---	---	---	---	----	---	----	----	-----	----	-----

TABLE 9. Analysis of soil mixtures for bush bean after second planting. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.6	5.8	720	2.0	22	0.03	1.8	1.0	<0.46	<0.05	53	2.6
LOM + 50 lbs. coml. N/A	---	---	----	2.0	---	----	----	0.9	-----	-----	---	1.8
LOM + 100 lbs. coml. N/A	---	---	----	1.9	---	----	----	0.9	-----	-----	---	1.6
LOM + 200 lbs. coml. N/A	---	---	----	2.0	---	----	----	2.0	-----	-----	---	3.6
LOM + 2.9 tons sludge/A	5.5	6.1	395	1.9	22	0.04	1.8	1.0	<0.3	<0.05	11	1.8
LOM + 5.8 tons sludge/A	5.6	6.3	720	2.2	24	0.08	1.9	1.0	<0.3	0.06	35	1.8
LOM + 11.7 tons sludge/A	5.8	6.4	2550	2.3	25	0.07	3.1	1.1	<0.4	<0.05	99	2.4
HOM	5.6	5.4	450	10.6	188	0.07	9.2	1.8	1.4	0.07	8	4.8
HOM + 2.9 tons sludge/A	5.7	5.5	645	13.0	198	0.08	9.7	1.9	1.5	<0.05	31	5.8
HOM + 5.8 tons sludge/A	5.7	5.7	1100	12.5	201	0.08	11.0	1.9	-----	<0.05	75	5.6
HOM + 11.7 tons sludge/A	5.9	5.9	1930	14.5	196	0.11	12.0	2.0	1.4	<0.05	195	6.2
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	---	---	----	----	---	----	----	---	-----	—	---	---
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	---	---	----	----	---	----	----	---	-----	—	---	---
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	---	---	----	----	---	----	----	---	-----	—	---	---
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	---	---	----	----	---	----	----	---	-----	—	---	---
Limed LOM	6.6	6.9	950	1.8	24	0.12	----	1.0	<0.3	<46.1	5	2.3
Limed HOM	6.9	6.6	1200	9.7	195	1.80	13.0	1.4	1.5	<0.2	27	4.8
Limed LOM + 200 lbs. coml. N/A	---	---	----	2.1	---	----	----	0.9	-----	-----	---	2.6
Limed LOM + 11.7 tons sludge/A	6.5	7.1	3000	2.2	21	0.44	5.1	1.0	0.4	<49.9	150	2.7
Limed HOM + 11.7 tons sludge/A	6.8	6.8	2450	13.5	197	2.61	14.5	2.0	1.6	<46.1	175	7.1
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	---	---	----	----	---	----	----	---	—	-----	---	---
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	---	---	----	----	---	----	----	---	—	-----	---	---

TABLE 9. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.8	5.2	29	380	167	75	200	0.90	1.68	22.6	59.9	0.05	<0.18	-----
LOM + 50 lbs. coml. N/A	---	3.6	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
LOM + 100 lbs. coml. N/A	---	2.5	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
LOM + 200 lbs. coml. N/A	---	3.5	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
LOM + 2.9 tons sludge/A	0.8	5.5	20	370	155	88	174	0.96	1.58	16.8	34.4	0.04	<0.18	-----
LOM + 5/8 tons sludge/A	0.7	8.0	18	370	152	90	148	0.79	1.55	15.9	28.5	<0.02	<0.18	-----
LOM + 11.7 tons sludge/A	0.4	61.0	18	360	145	127	115	0.79	1.48	14.8	22.6	0.03	<0.18	-----
HOM	1.9	19.0	155	730	395	82	617	<0.11	2.31	78.7	5.1	0.30	0.22	-----
HOM + 2.9 tons sludge/A	1.8	33.0	145	770	350	115	---	0.21	2.52	85.6	6.2	0.35	<0.18	-----
HOM + 5.8 tons sludge/A	2.0	45.0	120	770	320	125	398	0.64	2.87	0.1	10.8	0.54	<0.18	-----
HOM + 11.7 tons sludge/A	2.1	51.0	105	785	340	167	444	0.67	<0.51	0.1	14.8	0.58	<0.18	-----
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
Limed LOM	0.3	38.0	19	300	135	45	---	0.68	1.44	13.3	13.9	0.20	<0.18	<0.10
Limed HOM	2.1	54.0	82	730	400	75	419	0.53	3.12	0.1	5.7	0.52	0.26	<0.11
Limed LOM + 200 lbs. coml. N/A	---	92.2	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
Limed LOM + 11.7 tons sludge/A	0.4	117.5	18	280	145	117	---	0.82	1.73	12.5	19.4	0.06	0.26	<0.10
Limed HOM + 11.7 tons sludge/A	1.9	51.0	65	750	340	147	367	0.70	3.04	0.1	8.5	0.51	<0.18	<0.10
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	---	-----	---	---	---	---	---	-----	-----	----	----	-----	-----	-----

TABLE 10. Final analysis of soil mixtures for bush bean growth. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	CEC (meq per 100 g)	Total N (g/kg)	Inorg. C (g/kg)	Org. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH (mg/kg)
LOM	5.3	5.90	503	3.19	2.0	0.06	18	1.40	0.98	<0.40	0.08	<0.2	<39	9.2
LOM + 50 lbs. coml. N/A	5.6	5.89	269		2.0	0.09	17	1.29	0.95	<0.40	0.06	<0.2	<11	6.4
LOM + 100 lbs. coml. N/A	5.4	5.78	333		1.9	0.05	17	1.35	0.97	<0.40	0.06	<0.2	<10	5.2
LOM + 200 lbs. coml. N/A	5.2	5.78	575		1.9	0.05	19	1.34	1.03	<0.40	0.06	<0.2	<10	5.7
LOM + 2.9 tons sludge/A	5.7	6.04	479		2.0	0.05	24	1.67	1.00	<0.40	-----	<0.2	<10	4.6
LOM + 5.8 tons sludge/A	6.2	7.17	6,075	2.85	2.3	0.30	19	4.30	1.00	<0.40	0.23	<0.2	260	4.6
LOM + 11.7 tons sludge/A	6.3	6.61	3,425	3.17	2.2	0.05	17	2.90	1.00	0.48	0.24	<0.2	205	5.5
HOM	5.5	5.37	838	17.29	13.0	0.07	178	8.60	1.90	1.35	0.08	<0.2	<21	22.5
HOM + 2.9 tons sludge/A	5.7	5.36	1,450	17.57	14.0	0.06	200	9.70	2.00	1.50	-----	<0.2	<26	16.0
HOM + 5.8 tons sludge/A	5.9	5.50	2,150		15.0	0.06	199	9.90	2.10	1.60	0.24	<0.2	175	17.0
HOM + 11.7 tons sludge/A	6.1	5.67	2,950		15.0	0.08	199	10.50	2.10	1.70	0.32	<0.2	475	15.0
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	5.5	6.27	9,200		2.1	0.03	217	2.16	0.96	1.15	—	<0.2	1,900	28.5
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	4.1	4.45	4,175		2.0	0.05	224	2.05	0.93	7.45	10.50	300.0	18,500	12.0
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	5.5	5.48	7,150		14.0	0.07	183	14.00	2.00	2.30	1.30	0.3	2,950	12.0
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	5.4	5.27	------		13.0	0.04	181	11.00	1.90	10.35	12.00	1.3	11,650	64.5
Limed LOM	6.7	6.82	1,020	3.18	1.9	0.09	19	3.20	0.99	<0.40	0.03	<0.2	<10	5.2
Limed HOM	6.8	6.27	1,040	24.5	13.5	0.17	180	12.50	2.00	1.40	0.08	<0.2	<24	10.2
Limed LOM + 200 lbs. coml. N/A	6.8	4.45	2,070	3.24	2.0	0.07	35	3.20	0.99	<0.40	0.04	<0.2	120	6.4
Limed LOM + 11.7 tons sludge/A	6.1	5.48	905	3.28	2.1	0.05	22	1.92	1.00	<0.40	0.14	<0.2	40	5.3
Limed HOM + 11.7 tons sludge/A	6.9	6.80	3,600	24.15	14.0	0.28	197	12.50	2.00	1.55	0.33	<0.2	385	14.0
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	4.9	5.49	42,250		2.2	0.05	20	4.60	0.95	9.30	11.00	1.4	20,500	22.5
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	6.7	6.71	19,000		13.0	0.19	162	16.00	1.80	11.15	12.00	1.0	12,000	9.4

TABLE 10. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.6	5.8	10	330	155	67	157	1.6	3.4	1.6	48	0.1	<1	<0.10
LOM + 50 lbs. coml. N/A	0.7	<4.0	13	300	151	41	165	1.8	1.5	1.8	59	0.1	<1	<0.10
LOM + 100 lbs. coml. N/A	0.8	<4.0	13	315	147	43	155	1.7	1.6	1.8	54	0.1	<1	<0.10
LOM + 200 lbs. coml. N/A	0.8	<4.0	17	315	240	49	123	1.6	1.4	1.7	64	0.1	<1	<0.10
LOM + 2.9 tons sludge/A	0.7	<4.0	10	350	143	59	131	2.3	1.5	1.6	31	0.1	<1	<0.10
LOM + 5.8 tons sludge/A	0.3	150.0	4	240	149	108	62	1.2	1.4	1.6	10	<0.1	<1	<0.10
LOM + 11.7 tons sludge/A	0.3	47.5	23	360	132	116	107	1.3	1.4	1.5	19	0.1	<1	<0.10
HOM	2.1	38.0	200	650	370	67	390	1.4	3.5	12.4	19	0.6	<1	0.16
HOM + 2.9 tons sludge/A	2.0	70.0	165	790	360	94	400	1.7	3.5	12.4	16	0.6	<1	0.16
HOM + 5.8 tons sludge/A	2.0	84.0	110	720	340	128	360	1.7	3.4	12.2	15	0.6	<1	0.15
HOM + 11.7 tons sludge/A	2.1	100.0	117	760	370	169	340	1.8	3.5	15.2	16	0.6	<1	0.13
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	0.5	105.0	25	355	165	773	92	1.7	1.1	1.4	225	0.1	<1	<0.10
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	1.2	109.5	6	385	240	6,700	94	0.1	<0.5	0.8	175	<0.1	<1	0.22
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	2.1	150.0	125	730	400	850	360	1.8	3.3	13.0	22	0.6	<1	0.17
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	2.3	108.0	39	715	520	7,450	191	1.1	1.9	18.0	53	0.5	<1	0.29
Limed LOM	<0.2	135.0	27	275	141	37	67	2.3	1.3	1.0	11	0.1	<1	<0.10
Limed HOM	1.7	135.0	89	660	420	64	240	0.8	2.6	11.9	3	0.6	<1	<0.10
Limed LOM + 200 lbs. coml. N/A	0.4	95.0	36	315	240	41	70	2.5	1.2	1.5	19	0.1	<1	<0.10
Limed LOM + 11.7 tons sludge/A	0.5	77.0	25	340	142	77	117	1.5	1.5	1.7	24	0.1	<1	<0.10
Limed HOM + 11.7 tons sludge/A	1.6	165.0	59	686	390	150	275	1.0	2.5	10.4	6	0.5	<1	<0.10
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	1.2	61.0	<4	400	240	7,900	69	0.1	0.3	1.2	61	<0.1	<1	0.17
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	2.0	235.0	<4	940	480	8,150	230	1.1	2.3	5.0	12	0.4	<1	<0.10

TABLE 11. Analysis of soil mixtures for corn growth prior to planting. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	CEC (meq per 100 g)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.5	5.7	144	2.70	1.8	71	0.04	1.46	1.2	<0.001	0.07	<0.07	2.2	4.3
LOM + 87.5 lbs. coml. N/A	---	---	145	----	1.5	21	----	----	0.98	------	-----	-------	-----	72.5
LOM + 175 lbs. coml. N/A	---	---	147	----	1.5	20	----	----	0.99	------	-----	-------	-----	89.0
LOM + 350 lbs. coml. N/A	---	---	248	----	1.7	21	----	----	1.10	------	-----	-------	-----	21.2
LOM + 5.1 tons sludge/A	5.8	5.8	71	----	1.7	21	0.30	2.72	1.02	0.20	0.17	<0.09	45.0	3.3
LOM + 10.2 tons sludge/A	6.2	6.1	134	----	1.9	34	0.59	3.06	1.00	0.40	0.29	<0.09	61.3	4.1
LOM + 20.5 tons sludge/A	6.4	6.3	282	4.00	2.0	26	0.65	3.28	1.00	0.43	0.41	<0.09		7.4
HOM	5.5	5.4	960	8.38	13.1	381	0.04	8.82	2.0	0.001	0.10	<0.09	7.2	7.3
HOM + 5.1 tons sludge/A	5.9	5.5	173		11.1	216	0.18	3.63	1.75	1.3	0.22	<0.09	72.5	9.3
HOM + 10.2 tons sludge/A	6.1	5.8	272		11.3	208	0.47	3.50	1.77	1.40	0.43	<0.09	77.0	17.2
HOM + 20.5 tons sludge/A	6.4	6.0	362		12.6	218	0.95	3.83	1.99	1.52	0.61	<0.09	92.5	15.5
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	----	1.95	1.25	-----	----
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	----	18.85	3500.0	-----	----
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	----	3.10	1.55	-----	----
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	----	28.00	28.50	-----	----
Limed LOM	6.6	6.7	270	3.72	1.5	26	0.11	3.65	1.03	0.23	-----	<0.10	3.7	4.0
Limed HOM	7.2	6.4	1,650	----	11.5	165	1.33	3.19	1.84	1.45	0.08	<0.10	21.0	8.1
Limed LOM + 350 lbs. coml. N/A	6.9	6.6	3,000	----	----	32	—	—	—	—	—	<0.10	—	----
Limed LOM + 20.5 tons sludge/A	7.2	6.9	1,800		2.0	28	1.3	3.43	0.97	0.52	0.38	0.15	82.0	4.5
Limed HOM + 20.5 tons sludge/A	7.2	6.9	2,000		10.8	202	3.3	1.98	1.72	1.65	0.58	<0.10	155.0	35.5
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	------	25.00	54.00	-----	----
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	---	---	-----	----	----	---	----	----	----	------	24.50	2.80	-----	----

TABLE 11. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.6	<1.0	27	277	160	34	199	0.6	1.4	1.8	50	<0.04	<0.9	<0.10
LOM + 87.5 lbs. coml. N/A	----	1.2	16	---	---	---	---	---	---	----	----	-----	----	-----
LOM + 175 lbs. coml. N/A	----	1.1	17	---	---	---	---	---	---	----	----	-----	----	-----
LOM + 350 lbs. coml. N/A	----	2.2	26	---	---	---	---	---	---	----	----	-----	----	-----
LOM + 5.1 tons sludge/A	<0.8	<0.4	10	350	196	78	136	0.6	1.2	1.4	35	<0.04	<0.9	<0.10
LOM + 10.2 tons sludge/A	<0.8	<0.3	9	355	211	213	113	0.6	1.2	1.5	32	<0.04	<0.9	<0.10
LOM + 20.5 tons sludge/A	<0.8	0.4	8	400	208	167	130	0.6	1.1	1.5	42	<0.04	<0.9	<0.10
HOM	1.5	46.0	212	547	487	56	188	0.5	4.2	10.3	17	0.41	<1.5	<0.10
HOM + 5.1 tons sludge/A	1.5	47.0	86	655	440	107	235	0.6	2.9	12.0	8.2	0.45	<0.9	0.15
HOM + 10.2 tons sludge/A	<1.0	29.5	67	650	555	159	208	0.5	2.1	11.5	12	0.40	<0.9	<0.10
HOM + 20.5 tons sludge/A	<1.1	25.5	51	760	760	235	340	0.7	3.6	13.5	19	0.50	<0.9	<0.10
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----
Limed LOM	<0.8	3.7	10	299	186	44	111	0.4	1.3	0.7	9	0.06	<0.9	<0.10
Limed HOM	1.2	66.0	50	670	435	73	190	0.3	2.1	10.0	9	0.42	<0.9	<0.10
Limed LOM + 350 lbs. coml. N/A			15	---									<0.9	-----
Limed LOM + 20.5 tons sludge/A	<0.8	<0.4	7	327	187	170	82	0.4	1.4	1.7	16	<0.04	<0.9	<0.10
Limed HOM + 20.5 tons sludge/A		8.8	25	640	377	190		---	---	----		-----	<0.9	<0.10
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	----	----	---	---	---	---	---	---	---	----	----	-----	----	-----

TABLE 12. Analysis of soil mixtures for corn after second planting. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH_3 (mg/kg)
LOM	5.5	5.9	218	1.9	22	<0.03	1.5	1.1	<0.32	<0.2	<4	1.5
LOM + 87.5 lbs. coml. N/A	---	---	----	1.9	---	-----	----	1.0	-----	------	---	1.5
LOM + 175 lbs. coml. N/A	---	---	----	1.9	---	-----	----	1.0	-----	------	---	2.8
LOM + 350 lbs. coml. N/A	---	---	----	1.9	---	-----	----	1.0	-----	------	---	6.3
LOM + 5.1 tons sludge/A	5.7	6.3	550	2.1	22	0.05	1.8	1.1	<0.32	<0.2	23	1.4
LOM + 10.2 tons sludge/A	6.0	6.1	1850	2.4	23	0.05	2.5	1.1	<0.33	<0.2	78	1.4
LOM + 20.5 tons sludge/A	6.3	6.9	3980	2.3	25	-----	3.5	1.2	0.42	<0.2	135	1.3
HOM	5.7	5.5	305	15.0	196	0.07	8.8	1.9	1.35	<0.2	<7	1.9
HOM + 5.1 tons sludge/A	5.8	5.7	720	15.0	195	0.04	10.2	2.0	1.30	<0.2	52	2.5
HOM + 10.2 tons sludge/A	6.1	6.0	995	15.0	204	0.08	11.1	2.0	1.45	<0.2	145	2.4
HOM + 20.5 tons sludge/A	6.4	6.3	1675	16.2	202	0.03	11.4	2.1	1.70	<0.2	230	2.1
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	0.4	---	---
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	2115.0	---	---
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	0.3	---	---
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	2.6	---	---
Limed LOM	6.8	6.9	2210	1.9	22	-----	3.6	1.5	<0.32	<0.2	<4	1.1
Limed HOM	7.0	6.6	520	15.0	202	1.79	13.1	2.0	1.45	<0.2	<8	2.3
Limed LOM + 350 lbs. coml. N/A	---	---	----	2.0	---	-----	----	0.9	-----	------	---	1.1
Limed LOM + 20.5 tons sludge/A	7.0	7.3	5075	2.1	22	0.95	8.6	1.2	0.54	<43.6	175	1.3
Limed HOM + 20.5 tons sludge/A	7.2	7.0	2045	13.5	199	2.64	14.3	2.0	1.70	<46.1	205	2.7
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	55.7	---	---
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	---	---	----	----	---	-----	----	---	-----	0.4	---	---

TABLE 12. (continued)

Soil	Soluble nutrient and trace elements (mg/kg)													
	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
LOM	0.92	9.3	22	335	115	81	180	1.09	1.62	17.9	58.3	0.03	<0.18	
LOM + 87.5 lbs. coml. N/A	----	5.4	---	---	---	---	---	----	----	----	----	----	-----	----
LOM + 175 lbs. coml. N/A	----	33.0	---	---	---	---	---	----	----	----	----	----	-----	----
LOM + 350 lbs. coml. N/A	----	38.0	---	---	---	---	---	----	----	----	----	----	-----	----
LOM + 5.1 tons sludge/A	0.52	5.6	19	350	77	112	158	0.82	1.63	15.8	32.5	0.03	<0.18	
LOM + 10.2 tons sludge/A	0.41	1.4	18	375	89	114	120	0.73	1.55	18.9	24.9	0.03	<0.18	
LOM + 20.5 tons sludge/A	0.43	1.3	16	360	107	157	81	0.56	1.62	18.0	19.9	0.03	<0.18	
HOM	2.10	<1.9	185	655	192	110	416	0.15	2.99	81.3	7.7	0.32	<0.18	
HOM + 5.1 tons sludge/A	1.91	2.5	145	705	203	120	404	0.21	2.93	88.7	8.3	0.35	<0.18	
HOM + 10.2 tons sludge/A	2.06	2.4	105	810	132	145	415	0.48	3.15	0.1	10.0	0.33	<0.18	
HOM + 20.5 tons sludge/A	2.05	2.1	79	810	140	187	385	0.56	1.38	0.1	14.1	0.51	0.20	
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	----	----	---	---	---	---	---	----	----	----	----	----	-----	----
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	----	----	---	---	---	---	---	----	----	----	----	----	-----	----
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	----	----	---	---	---	---	---	----	----	----	----	----	-----	----
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	----	----	---	---	---	---	---	----	----	----	----	----	-----	----
Limed LOM	0.33	1.1	20	290	115	160	669	1.43	1.58	15.2	16.3	0.03	<0.18	
Limed HOM	2.11	2.3	88	760	193	195	426	0.44	3.15	0.1	7.2	0.34	0.22	0.11
Limed LOM + 350 lbs. coml. N/A	----	----	---	---	---	---	---	----	----	----	----	----	-----	----
Limed LOM + 20.5 tons sludge/A	0.41	1.1	16	270	112	107	69	0.64	1.73	16.5	20.0	0.04	<0.18	
Limed HOM + 20.5 tons sludge/A	1.29	1.3	42	760	137	82	317	0.47	2.76	0.1	14.2	0.43	0.24	
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	----		---	---	---	---	---	----	----	----	----	----	-----	----
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	----		---	---	---	---	---	----	----	----	----	----	-----	----

TABLE 13. Final analysis of soil mixtures for corn growth. The soils were low (LOM) and high (HOM) in organic matter content.

Soil	pH	Lime req. (pH units)	Electro-conductivity (μmho/cm)	Total N (g/kg)	Org. C (g/kg)	Inorg. C (g/kg)	Soluble Ca (g/kg)	Total P (g/kg)	Total S (g/kg)	Total Cr (g/kg)	Soluble Cr (mg/kg)	SO_4 (mg/kg)	NH (mg/kg)
LOM	4.5	6.45	280	1.9	29	0.07	1.38	1.0	<0.85	0.06	<0.2	<7	6.9
LOM + 87.5 lbs. coml. N/A	4.5	6.39	235	1.8	28	0.07	1.42	1.0	<0.85	0.06	<0.2	<7	3.6
LOM + 175 lbs. coml. N/A	4.3	6.46	1,000	1.8	27	0.06	1.40	1.0	<0.40	0.03	<0.2	<7	5.3
LOM + 350 lbs. coml. N/A	4.2	6.44	1,700	1.9	23	0.07	1.42	1.0	<0.40	0.03	<0.2	<7	14.0
LOM + 5.1 tons sludge/A	5.1	6.57	585	2.0	27	0.08	2.00	1.0	<0.40	0.14	<0.2	98	3.6
LOM + 10.2 tons sludge/A	5.6	6.80	2,100	2.2	>28	<0.06	2.40	1.0	<0.40	0.23	<0.2	41	4.7
LOM + 20.5 tons sludge/A	6.3	6.58	5,950	1.7	26	0.08	3.50	0.7	<0.40	0.33	<0.2	165	6.1
HOM	4.8	5.76	540	13.5	196	0.09	7.70	2.0	<0.80	0.12	<0.2	<7	7.8
HOM + 5.1 tons sludge/A	5.2	5.96	1,100	13.5	200	0.09	8.90	2.0	1.50	0.21	<0.2	135	7.8
HOM + 10.2 tons sludge/A	5.5	6.10	1,800	13.5	192	0.07	9.20	2.0	1.50	0.32	<0.2	------	7.7
HOM + 20.5 tons sludge/A	6.0	6.33	2,350		203	0.06	9.80	1.8	1.60	0.48	<0.2	------	6.0
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	5.1	6.21	7,750	1.9	35	0.06	2.70	0.9	1.60	1.45	0.3	------	8.8
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	3.9	4.69	------	2.4	23	0.06	5.95	0.9	13.25	17.00	20.5	13,500	6.0
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	5.3	5.72	6,650	11.5	207	0.06	10.70	1.7	3.25	2.37	0.4	5,275	7.6
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	4.6	5.28	50,500	11.5	169	0.06	12.75	1.7	18.7	21.00	1.8	13,250	45.5
Limed LOM	6.5	6.84	495	1.7	40	0.10	3.00	0.9	<0.40	0.04	<0.2	<13	4.3
Limed HOM	6.6	6.55	705	14.5	200	1.92	11.00	2.0	1.40	0.09	<0.2	<14	7.5
Limed LOM + 350 lbs. coml. N/A	5.7	6.65	4,400	2.1	19	0.03	3.30	1.0	<0.45	0.03	<0.2	------	4.6
Limed LOM + 20.5 tons sludge/A	# 6.9	7.29	7,250	2.5	27	0.65	5.50	1.0	0.60	0.40	<0.2	------	4.7 #
Limed HOM + 20.5 tons sludge/A	6.8	6.91	3,100	14.5	192	3.55	13.00	2.1	9.45	0.53	<0.2	1,650	7.4
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	3.4	4.04	59,500	2.1	23	0.05	3.25	0.9	24.75	15.50	1.9	19,000	3.7
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	6.3	6.46	35,000	13.3	140	0.14	18.00	1.8	18.45	22.50	0.3	13,000	7.1

TABLE 13. (continued)

Soil	Ni	NO_2+NO_3	P	Mg	K	Na	Fe	Pb	Cu	Zn	Mn	Cd	Mo	B
	Soluble nutrient and trace elements (mg/kg)													
LOM	0.7	8.1	28	310	122	37	132	1.3	1.3	1.3	36	0.1	<1	<0.10
LOM + 87.5 lbs. coml. N/A	0.7	<4.0	36	340	109	38	125	1.0	1.2	1.2	42	0.1	<1	<0.10
LOM + 175 lbs. coml. N/A	0.7	27.0	43	340	173	41	146	1.3	1.2	1.9	83	0.1	<1	<0.10
LOM + 350 lbs. coml. N/A	0.8	39.0	49	340	182	44	145	0.9	1.3	1.7	108	0.1	<1	<0.10
LOM + 5.1 tons sludge/A	0.6	<4.0	26	320	102	67	119	1.1	1.4	1.2	20	0.1	<1	<0.10
LOM + 10.2 tons sludge/A	0.3	31.5	26	300	94	97	88	1.0	1.3	1.0	19	0.1	<1	<0.10
LOM + 20.5 tons sludge/A	0.3	150.0	24	300	102	150	52	0.8	1.1	1.1	13	0.1	<1	<0.10
HOM	2.0	5.0	170	640	184	59	420	1.1	3.2	11.3	14	0.6	<1	0.17
HOM + 5.1 tons sludge/A	1.8	12.0	145	660	197	97	340	0.9	3.2	13.8	13	0.6	<1	0.16
HOM + 10.2 tons sludge/A	1.7	17.0	97	680	162	138	380	0.8	3.3	13.8	13	0.6	<1	0.13
HOM + 20.5 tons sludge/A	1.8	8.7	64	680	139	174	320	0.7	2.8	10.6	8	0.5	<1	0.11
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	0.7	6.4	17	370	130	1,020	92	0.9	1.0	1.3	86	0.2	<1	<0.10
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	1.1	<4.0	5	440	198	10,000	72	0.1	0.3	0.7	40	<0.1	<1	0.25
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	2.0	9.0	67	740	415	1,545	405	0.9	3.3	6.4	23	0.6	<1	0.16
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	2.0	6.6	26	720	520	11,250	131	0.6	1.0	4.9	61	0.2	<1	0.39
→ Limed LOM	0.3	13.5	16	280	103	40	82	1.2	1.4	1.9	13	0.1	<1	<0.10
Limed HOM	1.6	10.2	56	640	205	59	390	0.7	2.9	11.4	4	0.6	<1	<0.10
Limed LOM + 350 lbs. coml. N/A	0.3	160.0	33	320	149	43	88	0.8	1.1	0.7	17	0.1	<1	<0.10
Limed LOM + 20.5 tons sludge/A	0.5	225.0	23	250	102	158	52	1.0	1.5	2.2	12	0.1	<1	<0.10
Limed HOM + 20.5 tons sludge/A	1.5	40.0	60	670	147	199	310	1.6	2.7	10.8	11	0.5	<1	<0.10
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	1.7	<4.0	4.7	330	197	8,150	121	2.0	<0.4	0.8	190	<0.1	<1	0.31
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	1.9	105.0	11	780	450	12,000	199	0.9	2.0	3.8	18	0.3	<1	0.11

TABLE 14. Effects of various soil mixtures on seedling emergence. The soils were low (LOM) and high (HOM) in organic matter content. Significance of differences between means was determined using the LSD test.

Soil for bush bean growth	Bush bean seedling emergence (percentage of seeds planted) Planting No. 1	2	3
LOM	68	97	100
LOM + 50 lbs. coml. N/A	83	97	90
LOM + 100 lbs. coml. N/A	75	97	92
LOM + 200 lbs. coml. N/A	85	95	95
LOM + 2.9 tons sludge/A	83	95	95
LOM + 5.8 tons sludge/A	80	100	92
LOM + 11.7 tons sludge/A	78	95	92
HOM	63	92	97
HOM + 2.9 tons sludge/A	95	97	95
HOM + 5.8 tons sludge/A	90	92	97
HOM + 11.7 tons sludge/A	85	95	95
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	42	92	100
LOM + 5.8 tons sludge/A + 9.46 g Cr/kg dry soil	0	0	0
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	85	92	100
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	23	77	72
Limed LOM	58	97	95
Limed HOM	73	92	90
Limed LOM + 200 lbs. coml. N/A	10	95	95
Limed LOM + 11.7 tons sludge/A	35	92	100
Limed HOM + 11.7 tons sludge/A	88	90	97
Limed LOM + 11.7 tons sludge/A + 9.3 g Cr/kg dry soil	0	0	0
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	68	80	95
LSD 05	14	17	14

Soil for corn growth	Corn seedling emergence (percentage of seeds planted) Planting No. 1	2	3
LOM	90	95	89
LOM + 87.5 lbs. coml. N/A	100	95	95
LOM + 175 lbs. coml. N/A	52	95	92
LOM + 350 lbs. coml. N/A	90	95	77
LOM + 5.1 tons sludge/A	95	97	95
LOM + 10.2 tons sludge/A	62	97	95
LOM + 20.5 tons sludge/A	70	97	90
HOM	95	82	96
HOM + 5.1 tons sludge/A	88	90	100
HOM + 10.2 tons sludge/A	95	95	92
HOM + 20.5 tons sludge/A	70	97	97
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	88	97	97
LOM + 10.2 tons sludge/A + 16.2 g Cr/kg dry soil	0	0	0
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	63	100	97
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	30	32	72
Limed LOM	95	97	97
Limed HOM	92	95	100
Limed LOM + 350 lbs. coml. N/A	95	100	90
Limed LOM + 20.5 tons sludge/A	98	95	95
Limed HOM + 20.5 tons sludge/A	98	100	100
Limed LOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	0	0	0
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	85	70	87
LSD 05	18	19	15

Soil for tall fescue growth	Tall fescue seedling emergence (percentage of seeds planted) Percent ~~Planting No.~~
LOM	69
LOM + 80 lbs. coml. N/A	88
LOM + 160 lbs. coml. N/A	82
LOM + 320 lbs. coml. N/A	84
LOM + 4.7 tons sludge/A	90
LOM + 9.3 tons sludge/A	70
LOM + 18.7 tons sludge/A	80
HOM	76
HOM + 4.7 tons sludge/A	87
HOM + 9.3 tons sludge/A	77
HOM + 18.7 tons sludge/A	82
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	59
LOM + 9.3 tons sludge/A + 15.1 g Cr/kg dry soil	0
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	92
HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	0
Limed LOM	74
Limed HOM	84
Limed LOM + 320 lbs. coml. N/A	83
Limed LOM + 18.7 tons sludge/A	83
Limed HOM + 18.7 tons sludge/A	82
Limed LOM + 18.7 tons sludge/A + 14.9 g Cr/kg dry soil	0
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	83
LSD 05	13

TABLE 15. Effect of tannery sludge, trivalent chromium, and lime on the growth of tall fescue, bush beans, and corn. The soils were low (LOM) and high (HOM) in organic matter content. Significance of differences between means was determined by the LSD test (see Methods).

Plant	Soil mixtures	Dry Weight of tall fescue (mg/plant) First harvest	Second harvest	Third harvest
Tall fescue	LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	49	31	629
	HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	208	190	383
	HOM + 9.3 tons sludge/A + 14.8 g Cr/kg dry soil	----	--	----
	Limed LOM	429	349	602
	Limed HOM	850	307	578
	Limed LOM + 320 lbs. coml. N/A	1408	653	495
	Limed LOM + 18.7 tons sludge/A	595	528	704
	Limed HOM + 18.7 tons sludge/A	1074	693	1014
	Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	47	227	596
	LSP*	151	66	20

Plant	Soil mixtures	Dry Weight of bush beans (g/four plants) First harvest	Second harvest	Third harvest
Bush beans	LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	---	2.5	3.5
	HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	9.6	9.8	1.8
	HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	0.9	1.3	2.2
	Limed LOM	3.6	4.5	5.3
	Limed HOM	2.2	7.8	1.8
	Limed LOM + 200 lbs. coml. N/A	2.4	4.9	4.9
	Limed LOM + 11.7 tons sludge/A	1.8	4.0	3.7
	Limed HOM + 11.7 tons sludge/A	2.0	15.4	2.7
	Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	1.7	2.0	1.4
	LSP*	46	37	52

Plant	Soil mixtures	Dry Weight of corn (g/four plants) First harvest	Second harvest	Third harvest
Corn	LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	0.7	2.6	3.1
	HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	2.8	9.3	3.5
	HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	---	0.5	---
	Limed LOM	3.7	4.4	5.5
	Limed HOM	9.6	10.9	3.2
	Limed LOM + 350 lbs. coml. N/A	5.0	4.4	6.1
	Limed LOM + 20.5 tons sludge/A	3.2	3.5	3.5
	Limed HOM + 20.5 tons sludge/A	19.3	14.7	4.7
	Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	0.8	1.6	1.2
	LSP*	40	22	38

* Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 16. Nitrogenase dependent reduction of acetylene to ethylene in the root nodules of bush beans grown in various soil mixtures. The soils were low (LOM) and high (HOM) in organic matter content. Significance of differences between means was determined using the LSD test (see Methods).

Soil	Nitrogenase Activity (ppm C_2H_4 formed/hr.) First harvest	Second harvest	Third harvest
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	0.17	0.37	0.00
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	95.50	70.39	0.04
HOM + 5.8 tons sludge/A + 5.2 g Cr/kg dry soil	0.00	0.37	0.02
Limed LOM	17.28	0.73	0.02
Limed HOM	0.00	6.47	0.04
Limed LOM + 200 lbs. coml. N/A	0.22	0.06	0.01
Limed LOM + 11.7 tons sludge/A	0.83	0.04	0.00
Limed HOM + 11.7 tons sludge/A	0.00	11.51	0.01
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	0.00	0.04	0.06
*LSP 05	277	503	930

* Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 17. Analysis of the first cut of tall fescue. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	15	3.1	1.70	5.4	3.45	29.9	10.5	<1.02	1.81	<10.2	98.82	<15.3	443.1	<5.1	18.10
LOM + 80 lbs. coml. N/A	11	1.0	1.16	4.1	2.85	27.9	9.0	<1.00	1.42	<9.9	43.77	<14.9	265.5	<5.0	11.89
LOM + 160 lbs. coml. N/A	17	1.2	1.60	3.6	2.93	44.6	7.2	<0.95	1.80	<9.5	55.70	<14.2	246.3	<4.7	16.25
LOM + 320 lbs. coml. N/A	21	1.6	1.90	4.2	3.20	42.6	7.0	<1.00	-----	<10.0	58.10	<15.0	248.0	<5.0	17.44
LOM + 4.7 tons sludge/A	14	2.2	2.60	5.8	3.49	33.99	10.6	<1.00	1.84	<9.8	43.02	<14.7	167.4	<4.9	16.05
LOM + 9.3 tons sludge/A	12	1.6	1.76	4.8	2.89	30.00	10.9	<0.94	1.71	<9.4	40.87	<14.1	66.3	<4.7	11.72
LOM + 18.7 tons sludge/A	18	1.2	2.00	7.5	3.95	26.50	18.5	<1.00	1.48	4.6	40.90	<14.6	95.3	<4.9	13.24
HOM	14	3.9	1.90	3.5	2.40	33.50	7.8	<1.00	1.61	<9.9	44.64	<14.8	113.6	<5.9	16.79
HOM + 4.7 tons sludge/A	16	4.2	2.35	4.6	3.17	41.43	12.0	<0.95	2.00	<9.7	46.12	<14.2	47.4	<4.7	19.73
HOM + 9.3 tons sludge/A	16	3.7	2.00	5.1	3.25	48.19	12.7	<0.95	2.33	<9.5	45.80	<14.2	22.1	<4.7	22.10
HOM + 18.7 tons sludge/A	20	3.3	2.22	5.4	3.59	40.41	11.1	1.89	2.36	5.2	38.20	17.2	15.9	<4.9	23.45
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	19	0.8	3.2	2.8	1.50	22	<2.0	<1.0	2.04	5.00	-----	22.0	575.0	<5.0	10.3
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	12	3.4	1.97	5.2	2.45	33.50	11.3	1.75	2.48	5.5	30.80	16.9	144.0	<5.0	23.39
Limed LOM	12	2.4	2.18	4.9	3.30	25.50	11.3	1.51	2.31	5.0	31.74	<15.5	41.2	<4.9	9.73
Limed HOM	16	3.6	2.10	4.6	2.60	32.47	10.3	1.96	2.50	4.5	35.25	16.8	71.0	<4.9	13.13
Limed LOM + 320 lbs. coml. N/A	23	1.1	2.42	6.2	3.57	34.00	11.04	1.86	3.04	6.9	71.75	18.2	635.0	5.71	12.89
Limed LOM + 18.7 tons sludge/A	21	----	2.10	7.0	3.35	33.87	15.1	1.95	3.19	7.7	48.92	19.5	180.4	5.56	18.14
Limed HOM + 18.7 tons sludge/A	21	3.1	2.25	6.1	3.65	47.96	11.8	2.99	4.71	8.3	43.00	30.4	22.9	8.44	23.14
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	30	2.6	3.25	1.9	2.00	31.50	13.9	2.31	5.51	8.2	84.66	22.4	32.1	5.74	32.44
† LSP 05	17	24	19	9	16	26	59	20	20	20	28	32	79	42	30

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 18. Analysis of the second cut of tall fescue. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentration of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	9.4	3.1	2.1	7.2	6.21	13	<24.1	<0.96	1.67	4.62	58.0	<14.4	530	<4.8	14.7
LOM + 80 lbs. coml. N/A	6.3	1.6	3.6	7.8	6.60	13	<24.6	<0.98	1.61	4.21	38.7	<14.7	541	<4.9	19.2
LOM + 160 lbs. coml. N/A	5.2	1.1	2.3	7.4	4.65	13	<24.1	<0.98	1.52	3.73	26.3	<14.6	537	<4.9	14.4
LOM + 320 lbs. coml. N/A	5.1	0.8	1.0	5.0	3.39	13	<25.0	<1.00	1.45	3.02	25.6	<15.0	549	<5.0	9.4
LOM + 4.7 tons sludge/A	7.7	4.5	6.5	8.3	5.75	16	<24.5	<0.98	2.09	4.30	27.5	<14.7	305	<4.9	15.2
LOM + 9.3 tons sludge/A	6.6	3.7	5.0	7.8	5.10	15	<24.8	<0.97	1.90	4.19	37.2	<14.6	164	<4.9	15.9
LOM + 18.7 tons sludge/A	6.5	1.8	2.5	6.5	4.50	12	<24.3	<0.94	2.17	4.64	43.6	<14.5	208	<5.2	12.0
HOM	5.8	6.6	2.4	7.5	6.70	10	35.7	<0.97	1.57	3.39	48.1	<14.6	536	<4.9	19.5
HOM + 4.7 tons sludge/A	5.8	4.2	2.9	7.0	5.90	11	<24.4	<0.97	2.23	3.80	17.0	<14.6	216	<4.9	18.8
HOM + 9.3 tons sludge/A	5.6	3.7	2.8	6.2	5.62	13	<24.6	<0.98	1.80	3.66	34.5	<14.8	94	<4.9	17.7
HOM + 18.7 tons sludge/A	6.9	2.6	1.9	8.9	6.30	13	<26.3	<0.96	2.02	1.37	23.4	<14.4	60	<4.8	18.4
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	10.2	1.7	4.6	4.6	3.10	16	<24.4	<0.98	2.97	5.05	61.0	<14.6	536	<4.9	11.7
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	7.3	3.3	3.8	7.5	5.35	15	<24.9	1.31	1.82	4.77	23.6	<14.9	537	<5.0	26.4
Limed LOM	6.7	3.8	2.1	7.8	5.20	12	<24.9	<0.95	2.02	4.24	51.4	<14.7	61	<4.9	15.8
Limed HOM	6.8	3.7	2.2	7.9	5.95	10	<24.9	<1.00	2.04	4.43	22.9	<14.9	66	<5.0	15.0
Limed LOM + 320 lbs. coml. N/A	5.4	0.9	2.5	----	4.54	9	<24.9	<1.00	2.28	4.61	20.3	<14.9	73	<5.0	19.9
Limed LOM + 18.7 tons sludge/A	8.2	2.2	3.0	8.8	5.14	14	<24.9	<1.00	2.53	5.24	49.1	<14.9	438	<5.0	26.7
Limed HOM + 18.7 tons sludge/A	6.8	2.5	2.2	7.8	5.08	12	<25.7	<0.99	2.56	4.82	21.3	<14.9	74	<5.0	16.6
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	8.0	1.4	4.0	2.4	2.24	13	<28.9	<0.99	3.85	5.05	48.7	<14.8	126	<5.0	14.0
† LSP 05	13	25	24	29	19	29	70	-----	29	15	147	-----	33	-----	30

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 19. Analysis of the third cut of tall fescue. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	6.2	3.7	<0.9	5.00	5.01	6.5	8.9	<1.00	2.2	2.67	141	<15	405	<5.0	14.4
LOM + 80 lbs. coml. N/A	5.6	3.3	3.6	6.48	5.37	8.0	8.3	<1.00	4.6	4.27	68	<15	>110	6.7	14.9
LOM + 160 lbs. coml. N/A	4.7	2.5	3.1	6.90	5.23	9.7	8.5	1.30	6.0	4.51	103	16	>110	7.3	26.6
LOM + 320 lbs. coml. N/A	4.6	1.5	2.3	8.25	4.92	11.1	8.8	1.57	6.0	4.89	93	18	>110	7.6	20.5
LOM + 4.7 tons sludge/A	5.8	6.6	4.5	7.36	5.59	8.0	12.9	1.49	5.8	5.39	183	18	277	7.4	16.4
LOM + 9.3 tons sludge/A	6.1	6.1	5.0	6.05	5.34	10.2	10.5	1.33	6.3	6.63	59	22	150	8.2	12.0
LOM + 18.7 tons sludge/A	5.5	4.5	3.4	7.36	5.57	7.6	9.1	1.44	6.2	5.80	57	22	266	8.7	12.3
HOM	6.3	9.6	2.7	6.45	4.74	7.1	13.2	1.15	2.9	3.21	72	<15	431	<5.0	18.9
HOM + 4.7 tons sludge/A	6.5	7.7	4.3	6.61	5.22	7.9	14.2	1.66	5.6	5.64	80	18	217	7.4	14.5
HOM + 9.3 tons sludge/A	5.3	7.4	3.4	6.42	5.03	8.3	14.2	2.02	5.6	5.30	55	19	108	7.9	13.6
HOM + 18.7 tons sludge/A	5.6	5.7	2.7	7.20	7.01	7.9	11.8	2.10	6.3	5.53	52	22	86	8.6	17.4
LOM + 9.3 tons sludge/A + 1.37 g Cr/kg dry soil	7.4	2.1	4.1	3.86	3.78	8.5	12.4	1.33	20.5	6.69	211	24	>110	9.2	15.8
HOM + 9.3 tons sludge/A + 1.34 g Cr/kg dry soil	4.7	5.1	3.7	7.14	5.28	6.2	15.1	2.93	7.8	6.10	64	23	>246	8.6	20.8
Limed LOM	5.8	5.1	1.0	5.95	5.26	8.2	7.1	1.11	4.1	6.16	59	25	62	6.5	15.0
Limed HOM	6.5	7.0	2.2	6.81	4.56	7.8	10.4	1.55	4.0	6.05	60	25	32	7.3	13.2
Limed LOM + 320 lbs. coml. N/A	4.9	3.3	2.9	6.91	5.46	9.2	7.8	1.50	5.3	6.94	63	30	80	7.8	19.5
Limed LOM + 18.7 tons sludge/A	6.3	3.5	3.4	>11.00	6.26	9.6	10.0	1.52	5.2	7.13	73	30	507	7.8	17.5
Limed HOM + 18.7 tons sludge/A	5.3	4.6	2.7	10.04	8.61	7.1	10.1	2.36	5.2	6.59	73	27	114	7.8	26.0
Limed HOM + 18.7 tons sludge/A + 14.6 g Cr/kg dry soil	6.5	1.4	6.4	2.67	3.47	8.2	10.4	2.35	10.8	5.90	62	23	263	9.1	14.3
† LSP 05	19.1	42.0	40.3	19.5	15.5	16.6	27.9	20.7	43.9	18.8	121	21	39	17	48.2

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 20. Analysis of the first harvest of bush bean. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	26	2.4	1.1	15.1	3.4	16	26	<0.99	<1.36	<9.89	198	<14.8	263	<4.94	31
LOM + 50 lbs. coml. N/A	17	1.9	1.6	12.6	2.8	12	20	<0.99	<1.10	<9.85	66	<14.8	147	<4.93	31
LOM + 100 lbs. coml. N/A	36	2.5	2.0	12.5	3.2	22	20	<0.98	1.04	<9.81	77	<14.7	181	<4.90	32
LOM + 200 lbs. coml. N/A	<7	2.3	1.9	12.6	3.6	22	18	<0.99	1.16	<9.89	83	<14.8	289	<4.95	33
LOM + 2.9 tons sludge/A	33	2.5	2.4	17.1	3.2	16	25	<0.95	1.29	<10.00	87	<14.2	133	<4.72	36
LOM + 5.8 tons sludge/A	29	2.8	2.2	17.3	3.0	17	24	<0.99	1.28	<10.77	87	<14.8	85	<4.93	33
LOM + 11.7 tons sludge/A	55	2.3	2.7	21.2	4.0	22	26	<0.98	3.96	<9.78	178	<14.7	122	<4.88	29
HOM	25	3.1	1.5	17.5	3.3	14	17	<0.95	<1.03	<9.47	80	<14.2	59	<4.73	22
HOM + 2.9 tons sludge/A	41	4.1	2.2	17.1	3.4	22	21	<0.94	1.59	<9.43	107	<14.1	51	<4.72	25
HOM + 5.8 tons sludge/A	<20	5.9	2.7	18.8	3.6	23	17	<0.99	1.70	<9.94	113	<14.9	30	<4.97	31
HOM + 11.7 tons sludge/A	34	3.0	2.5	20.3	3.4	18	19	<0.97	2.43	44.5	12	<14.6	28	16.6	35
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	63	5.8	----	8.9	5.5	22	20	2.28	10.1	<22.8	220	<34.2	717	<11.4	40
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	<8	3.6	5.9	17.8	3.0	24	20	<0.97	1.63	<9.71	92	<14.6	96	<4.85	45
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	51	3.0	20.8	10.1	6.0	39	18	<0.95	7.55	<12.32	108	<14.3	162	<4.76	74
Limed LOM	35	1.9	1.8	19.9	4.1	22	12	<0.97	2.21	<12.18	296	<14.7	74	<4.90	13
Limed HOM	31	1.8	1.3	9.9	1.6	11	6	<0.91	1.04	<9.12	53	<13.7	7	<4.56	9
Limed LOM + 200 lbs. coml. N/A	46	1.9	2.3	22.8	4.3	26	10	<0.99	1.80	<9.90	113	<14.7	60	<4.95	11
Limed LOM + 11.7 tons sludge/A	39	<0.5	2.4	24.2	4.1	22	14	<0.95	3.71	<9.49	135	<14.2	156	<4.74	13
Limed HOM + 11.7 tons sludge/A	34	1.8	2.1	16.7	2.5	17	6	<0.97	1.78	<9.43	46	<14.7	9	<4.86	10
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry sludge	40	1.9	----	16.1	4.5	41	15	<0.94	9.85	<9.71	80	<4.1	18	5.48	22
† LSP 05	19	55	26	17	21	31	23	-----	171	------	206	-----	51	146	26

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 21. Analysis of the second harvest of bush bean. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	27	2.2	1.0	20.7	3.59	14	30	<1.17	2.9	5.7	131	<17.4	240	7.1	27
LOM + 50 lbs. coml. N/A	20	1.6	1.4	17.2	2.90	14	29	<0.95	2.7	6.2	116	<14.3	218	<4.8	41
LOM + 100 lbs. coml. N/A	19	1.6	1.8	18.1	3.05	14	<24	<0.95	2.7	6.6	119	<14.2	257	5.6	43
LOM + 200 lbs. coml. N/A	21	1.7	1.6	20.3	3.34	17	<25	<0.99	3.0	6.8	168	<14.9	555	5.9	41
LOM + 2.9 tons sludge/A	24	1.4	1.6	20.9	3.38	16	<26	<0.97	3.3	6.7	137	<14.5	123	<5.2	45
LOM + 5.8 tons sludge/A	25	1.5	1.6	22.9	3.45	15	33	<0.96	3.1	6.0	109	<14.4	93	<4.8	41
LOM + 11.7 tons sludge/A	36	1.4	1.5	28.0	4.23	19	30	<0.93	5.1	6.1	≥513	<14.0	114	<4.7	34
HOM	29	3.4	3.4	21.8	3.70	15	25	<0.94	4.5	5.2	107	<14.1	111	<4.7	29
HOM + 2.9 tons sludge/A	30	3.4	2.1	22.5	4.25	20	35	<0.95	3.4	5.1	122	<14.3	112	<4.8	30
HOM + 5.8 tons sludge/A	27	3.2	3.0	30.6	4.10	21	35	<0.96	2.9	4.5	176	<14.4	71	<4.8	34
HOM + 11.7 tons sludge/A	30	3.1	3.6	29.4	4.50	24	32	<0.97	3.6	4.7	134	<14.5	71	<4.8	44
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	34	1.1	6.4	18.3	4.55	17	39	<0.97	6.9	5.3	290	<14.6	2014	<4.9	32
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	32	3.1	5.1	29.2	4.50	20	42	<0.99	3.9	4.6	123	<14.9	135	<5.0	43
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	48	3.6	25.0	11.4	4.29	54	47	1.39	9.9	10.1	123	23.8	231	8.9	113
Limed LOM	39	1.2	1.7	31.9	4.30	20	<29	<0.99	4.5	5.5	141	<14.8	78	<4.9	21
Limed HOM	33	2.2	1.8	38.9	4.20	25	<24	<0.93	4.9	4.4	138	<14.0	25	<4.7	41
Limed LOM + 200 lbs. coml. N/A	38	1.1	1.6	38.3	4.20	23	<28	<0.96	4.1	4.7	151	<14.4	94	<4.8	20
Limed LOM + 11.7 tons sludge/A	40	1.0	1.7	40.4	4.20	17	36	<0.99	4.7	5.6	168	<14.5	118	<4.8	16
Limed HOM + 11.7 tons sludge/A	28	2.2	1.7	37.3	4.15	21	<26	<0.97	6.3	4.4	131	<14.6	29	<4.8	39
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	42	1.5	19.2	21.6	2.95	51	30	<0.96	22.6	6.5	125	<14.4	68	5.3	43
† LSP 05	12	39	27	38	14	28	40	318	123	16	137	209	29	20	55

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 22. Analysis of the third harvest of bush bean. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	35	2.5	2.3	21	3.97	22	22	2.56	6.0	12.7	145	<14.5	308	16.1	71
LOM + 50 lbs. coml. N/A	27	2.2	1.8	20	3.78	19	19	2.29	6.2	16.1	432	<14.6	321	15.4	78
LOM + 100 lbs. coml. N/A	23	2.8	3.6	16	4.26	14	22	1.80	4.5	12.2	115	<14.8	397	14.3	79
LOM + 200 lbs. coml. N/A	23	2.9	3.1	21	3.59	19	20	1.80	4.6	11.9	191	<14.8	701	13.1	69
LOM + 2.9 tons sludge/A	26	2.2	1.9	26	4.19	17	27	1.58	4.3	9.5	138	<14.7	197	11.0	77
LOM + 5.8 tons sludge/A	25	1.9	2.1	29	4.31	13	23	1.44	4.1	8.5	122	<14.8	140	9.8	67
LOM + 11.7 tons sludge/A	36	1.8	2.1	37	4.49	19	21	1.98	5.4	9.9	126	<14.6	109	11.9	50
HOM	46	4.7	1.9	32	5.31	32	24	2.76	6.5	11.9	190	<14.9	211	14.6	58
HOM + 2.9 tons sludge/A	50	4.3	3.0	33	5.34	25	26	2.22	6.1	16.2	200	<14.7	183	12.4	67
HOM + 5.8 tons sludge/A	47	4.0	3.4	34	4.90	30	22	2.47	6.5	10.7	136	<14.8	137	14.0	67
HOM + 11.7 tons sludge/A	48	3.4	3.6	44	4.63	29	19	2.81	7.2	11.8	140	<14.7	102	15.1	78
LOM + 5.8 tons sludge/A + 0.85 g Cr/kg dry soil	56	2.6	7.0	22	3.77	21	24	2.49	8.6	10.8	200	<14.6	1399	13.2	39
HOM + 5.8 tons sludge/A + 0.84 g Cr/kg dry soil	48	3.3	6.4	32	4.60	37	22	3.35	11.0	14.1	151	<14.7	210	18.5	88
HOM + 5.8 tons sludge/A + 9.2 g Cr/kg dry soil	51	3.5	24.8	17	3.76	44	23	6.17	20.1	25.7	147	<14.7	189	34.6	67
Limed LOM	41	1.9	1.7	31	4.86	16	16	2.10	5.9	9.6	129	<14.7	86	12.3	25
Limed HOM	46	2.6	2.6	<3.6	4.17	2	19	2.69	8.0	11.8	149	<16.8	38	14.3	39
Limed LOM + 200 lbs. coml. N/A	39	1.6	2.1	<4.1	4.03	2	16	2.40	6.5	10.6	126	<14.7	103	14.0	26
Limed LOM + 11.7 tons sludge/A	43	1.4	2.3	<4.2	4.26	<17	18	2.16	6.1	9.7	141	<14.5	96	12.3	19
Limed HOM + 11.7 tons sludge/A	69	3.8	2.9	38	3.93	32	22	2.72	7.7	11.6	160	<15.0	73	14.2	39
Limed HOM + 11.7 tons sludge/A + 9.1 g Cr/kg dry soil	51	2.8	10.8	21	3.03	47	21	5.30	18.5	21.8	130	<14.8	72	28.7	31
† LSP 05	48	62.2	29.2	48	11.8	818	26	21.9	22.6	38.4	81	‡-----	30	18.6	34

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 23. Analysis of the first harvest of corn. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	14	2.9	0.8	0.3	3.0	52.9	0.7	1.0	2.23	4.1	42	13.7	132	4.6	32
LOM + 87.5 lbs. coml. N/A	20	1.9	1.5	3.8	2.2	49.4	7.4	<1.0	2.04	4.3	58	<14.4	72	<4.8	29
LOM + 175 lbs. coml. N/A	42	2.2	2.1	4.5	2.7	70.4	7.9	<1.1	2.58	6.6	78	<17.4	114	<5.4	54
LOM + 350 lbs. coml. N/A	38	2.2	2.4	4.2	2.4	50.1	7.9	1.1	3.11	<8.5	76	21.9	125	6.4	54
LOM + 5.1 tons sludge/A	25	2.1	1.6	6.3	4.0	46.5	8.2	1.1	3.09	<9.4	60	19.3	64	6.2	51
LOM + 10.2 tons sludge/A	41	<1.1	2.1	8.0	4.3	44.5	10.6	1.3	3.14	<9.4	75	18.4	83	5.3	36
LOM + 20.5 tons sludge/A	45	<0.4	2.3	9.9	4.5	45.0	12.2	1.3	3.18	<9.5	83	17.4	98	5.1	31
HOM	14	7.2	1.5	5.2	1.7	36.2	6.5	1.0	2.00	3.8	43	<14.0	42	<4.7	26
HOM + 5.1 tons sludge/A	20	6.3	2.0	5.6	2.2	56.4	10.6	1.5	3.40	<9.5	86	21.4	30	6.4	40
HOM + 10.2 tons sludge/A	24	4.1	2.1	5.8	2.4	54.9	8.3	1.5	2.85	<9.7	76	18.9	18	5.1	40
HOM + 20.5 tons sludge/A	22	5.3	2.4	6.6	2.1	46.6	9.4	1.7	3.11	<9.9	60	19.7	52	5.4	42
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	19	2.2	7.2	5.0	3.6	32.6	9.6	<1.2	4.23	<12.1	78	<18.1	480	<6.0	30
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	23	8.7	2.7	6.1	2.2	53.0	7.7	1.1	2.45	<9.9	52	<14.9	42	<5.0	42
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	--	----	----	----	----	----	----	----	-----	-----	---	-----	---	----	--
Limed LOM	18	2.0	1.4	6.5	3.5	44.7	4.6	<1.0	1.84	<9.7	118	<14.6	63	<4.9	11
Limed HOM	20	4.3	1.7	4.9	1.8	51.0	11.5	<1.0	2.83	<9.7	65	<26.3	9	<5.0	19
Limed LOM + 350 lbs. coml. N/A	44	2.0	2.0	7.1	3.9	31.6	10.9	1.1	2.87	<9.4	74	<16.1	54	<4.8	22
Limed LOM + 20.5 tons sludge/A	40	1.5	2.2	9.8	5.4	32.0	16.8	1.1	3.02	<9.9	81	<16.7	117	<5.2	22
Limed HOM + 20.5 tons sludge/A	24	2.4	1.8	6.5	2.7	38.4	7.6	1.2	2.82	<9.9	98	<17.2	15	<6.5	24
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	33	3.5	17.2	1.4	2.5	35.3	13.4	<1.1	8.66	<11.3	67	<16.9	42	<5.6	36
† LSP 05	25	19	26	12	14	61	77	27	38	19	52	25	18	33	48

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 24. Analysis of the second harvest of corn. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	28	1.2	0.7	6.8	5.7	48	<25	<0.99	4.75	7.59	99	<15	167	<5.0	50
LOM + 87.5 lbs. coml. N/A	20	0.9	1.1	6.2	5.1	45	<24	<0.97	6.22	6.29	96	<15	132	<4.8	39
LOM + 175 lbs. coml. N/A	30	0.9	2.1	5.2	5.1	53	<24	<0.98	7.25	9.16	96	<15	367	6.9	112
LOM + 350 lbs. coml. N/A	35	0.9	2.7	6.4	5.8	47	<24	<0.97	6.92	8.75	128	<15	709	7.4	139
LOM + 5.1 tons sludge/A	21	0.9	1.1	8.8	5.7	45	<24	<0.98	6.39	6.35	65	<15	72	<4.9	76
LOM + 10.2 tons sludge/A	26	1.1	1.6	11.8	6.1	50	<24	1.10	5.77	7.08	71	<15	93	6.8	46
LOM + 20.5 tons sludge/A	27	1.0	1.6	13.1	6.0	47	<24	0.98	4.60	6.71	66	<15	86	<4.9	26
HOM	12	5.9	1.3	5.5	2.4	46	<24	<0.98	5.40	4.82	40	<15	82	<5.3	30
HOM + 5.1 tons sludge/A	12	4.6	1.9	6.4	2.7	44	<24	<0.97	3.72	4.47	33	<15	69	<4.9	32
HOM + 10.2 tons sludge/A	14	3.6	1.5	5.4	2.9	39	<24	1.10	3.54	4.65	41	<15	38	<4.9	36
HOM + 20.5 tons sludge/A	14	2.8	1.5	9.7	3.7	33	<24	<0.98	4.44	4.68	53	<15	36	<4.9	37
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	26	0.8	2.9	5.7	4.4	32	<25	1.57	6.32	6.50	76	<15	303	<4.9	52
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	10	3.0	1.3	4.6	2.7	47	<24	1.09	4.14	5.62	37	<15	60	<4.9	37
HOM + 10.2 tons sludge/A + 16.1 g Cr/kg dry soil	--	----	----	3.2	4.0	31	<24	<0.98	5.40	8.89	55	<15	139	9.1	66
Limed LOM	21	0.9	1.5	9.3	6.4	34	<25	<0.99	4.41	6.11	62	<15	56	<4.9	16
Limed HOM	11	2.2	1.2	7.2	2.9	35	<24	1.01	3.44	4.64	32	<15	17	<4.9	21
Limed LOM + 350 lbs. coml. N/A	28	1.0	1.8	9.1	5.5	48	<24	1.31	4.95	7.29	63	<17	81	5.5	36
Limed LOM + 20.5 tons sludge/A	26	0.9	2.0	16.5	7.3	40	<25	1.08	4.26	6.95	73	<15	79	<5.0	15
Limed HOM + 20.5 tons sludge/A	18	1.6	1.4	8.1	2.5	25	<25	1.08	4.16	4.77	<24	<15	17	<4.9	22
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	21	0.9	4.2	1.3	3.0	31	<30	<0.99	8.50	5.17	<29	<15	26	<4.9	19
† LSP 05	19	11	25	107	69	33	---	33	79	43	71	---	74	84	24

† Least significant percentage at the 5% level of statistical significance (see Methods).

TABLE 25. Analysis of the third harvest of corn. Soils were low (LOM) or high (HOM) in organic matter content. Significance of difference between means was determined using the LSD test (see Methods).

Soil	Concentrations of elements (g/kg)						Concentrations of elements (mg/kg)								
	N	P	S	Ca	Mg	K	B	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
LOM	20	1.1	0.81	6.2	4.22	39	8.8	3.03	7.37	13.4	103	<14.6	125	18.0	43.5
LOM + 87.5 lbs. coml. N/A	14	1.1	0.88	5.7	3.93	32	9.8	2.25	5.53	10.3	81	<14.5	118	14.3	44.3
LOM + 175 lbs. coml. N/A	30	1.5	1.68	6.7	5.27	40	13.7	4.59	10.53	19.1	185	<14.6	499	25.4	67.1
LOM + 350 lbs. coml. N/A	29	1.3	1.92	6.6	4.32	43	15.8	4.09	9.28	19.6	121	<14.5	489	21.8	67.6
LOM + 5.1 tons sludge/A	13	1.1	1.04	7.1	5.73	22	11.4	2.32	5.90	10.2	96	<14.8	62	14.3	37.9
LOM + 10.2 tons sludge/A	26	1.3	1.58	10.5	7.15	34	10.8	2.75	6.51	12.1	113	<14.6	90	14.7	49.1
LOM + 20.5 tons sludge/A	31	1.3	1.79	14.7	7.17	36	13.5	3.12	7.31	13.0	128	<14.6	101	15.7	36.9
HOM	14	5.5	1.41	8.3	3,23	43	13.0	3.57	8.06	13.6	109	<14.2	130	17.8	37.0
HOM + 5.1 tons sludge/A	17	4.6	1.96	10.0	3.54	39	13.9	3.57	8.09	12.9	67	<14.8	132	17.3	35.3
HOM + 10.2 tons sludge/A	17	3.4	2.19	10.5	4.75	30	11.7	2.52	5.64	10.0	69	<14.8	96	16.8	36.0
HOM + 20.5 tons sludge/A	11	4.6	1.23	7.8	4.31	29	9.8	2.47	5.46	8.7	67	<14.7	74	13.4	26.6
LOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	22	1.6	2.09	5.5	3.93	43	12.9	5.03	9.86	15.5	118	<14.7	195	20.1	63.3
HOM + 10.2 tons sludge/A + 1.47 g Cr/kg dry soil	19	1.5	1.86	7.4	3.92	43	15.4	5.58	10.00	15.9	119	<14.8	202	20.3	>47.8
→ Limed LOM	20	1.7	1.20	10.9	6.76	21	11.2	2.11	4.96	9.5	120	<14.7	57	10.6	17.7
Limed HOM	14	2.1	1.53	13.2	3.72	43	11.7	3.08	6.39	10.7	82	<14.7	42	18.5	22.3
Limed LOM + 350 lbs. coml. N/A	29	1.3	1.77	9.9	5.93	40	10.6	3.60	7.89	15.0	114	<14.8	70	18.6	34.2
Limed LOM + 20.5 tons sludge/A	27	1.2	1.80	16.9	8.16	28	13.2	2.66	5.91	11.6	97	<14.7	76	13.0	14.9
Limed HOM + 20.5 tons sludge/A	20	1.4	1.55	10.9	8.37	19	12.2	2.60	5.32	8.0	135	<14.7	108	10.8	23.6
Limed HOM + 20.5 tons sludge/A + 16.0 g Cr/kg dry soil	20	1.0	4.54	0.4	2.76	21	15.1	2.84	8.51	9.8	63	<14.6	91	12.7	23.1
† LSP 05	31	50	43	156	27.7	22	44.1	25.3	43.8	33.7	93	-----	69	51.9	36.4

† Least significant percentage at the 5% level of statistical significance (see Methods).