AN ABSTRACT OF THE THESIS OF

NANCY McCOMBS COTTRELL for the degree MASTER OF SCIENCE
(Name of student) (Degree)

in Soil Science presented on March 7, 1975
(Major Department) (Date)

Title: DISPOSAL OF MUNICIPAL WASTES ON SANDY SOIL: EFFECT ON PLANT NUTRIENT UPTAKE

Abstract approved: Redacted for Privacy
Dr. V. Van Volk

Solid municipal waste was applied to Sagehill sand at rates of 0, 100, 200, and 400 tons/acre (0, 67, 133, and 267 tons dry matter). Sewage sludge (2% solids) was applied at 55 gallons per ton of solid waste. Hyslop winter wheat was planted as a cover crop in October 1971 and followed by spring-seeded Fawn fescue and Sernac alfalfa. Ammonium sulfate fertilizer was applied and the plots were irrigated for two crop seasons.

The solid waste decomposed rapidly, with only plastic, rubber, and rusted metal remaining on the plots by the end of the first growing season.

The soil bulk density decreased with the addition of solid waste, while the organic matter content and moisture retention increased. Effective wind erosion control was obtained with all solid waste applications.

Alfalfa and fescue yields of 5 to 6 tons/acre were produced during the first growing season with solid waste treatments of 0, 100, and 200 tons/acre; yields were reduced when 400 tons solid waste were applied. The maximum alfalfa and fescue yields were obtained with the addition of 400 lb N/acre and 1000 lb N/acre, respectively. Higher nitrogen applications decreased fescue yields due to increased soil acidity and consequent increased Mn and Zn uptake. Invasion by weeds decreased yields on plots which received inadequate irrigation early in the season.

Plant content of N, P, S, Ca, Mg, K, Fe, and Cu was not affected by the waste treatments. Mn and Zn uptake by wheat, fescue, and alfalfa increased with waste addition and with nitrogen fertilization. Zn uptake from the soil with 400 tons solid waste per acre approached excessive levels (over 200 ppm) during the first season. B uptake by wheat and fescue reached toxic levels while B uptake by alfalfa increased only slightly. Mo uptake by alfalfa grown with the higher waste treatments reached levels potentially hazardous to livestock during the first growing season, but decreased to normal the second year. Co and Cr uptake by alfalfa and fescue was affected very little by the waste additions.

Soil pH decreased slightly with waste application and appreciably with nitrogen fertilization. Soil Na content exceeded 3 me/100g early in the season in the soils which received 400 tons solid waste per acre, but decreased rapidly as Na was leached with irrigation water. Levels of extractable soil Fe and Cu increased 50-fold with the highest waste treatment, while the extractable soil Zn increased 1000-fold. But soil levels of Fe, Cu, and Zn were not excessive with the lower waste treatments, and decreased to acceptable levels in all the soils within the first growing season.

Soil B content increased up to 60-fold with the addition of solid waste. The B remained soluble in the soil and followed water movement patterns. The hot water extractable B decreased to 0.8 ppm or less within the first season in the soil with the lower waste treatments, but remained greater than 2 ppm after two years in the soils which received 400 tons solid waste per acre.

Crop production on Sagehill sand after the incorporation of up to 200 tons solid waste per acre appeared feasible with a boron-tolerant crop such as alfalfa and with irrigation adequate to meet crop needs. Higher rates of solid waste application decreased yields and added hazardous amounts of Zn, B, Na, and Mo to the soil.

Disposal of Municipal Wastes on Sandy Soil:
Effect on Plant Nutrient Uptake

by

Nancy McCombs Cottrell

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1975

APPROVED:

Redacted for Privacy

Associate Professor of Soil Science
in charge of major

Redacted for Privacy

Head of Department of Soil Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented March 7, 1975

Typed by Velda D. Mullins for Nancy McCombs Cottrell

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

DISPOSAL OF MUNICIPAL WASTES ON SANDY SOIL: EFFECT ON PLANT NUTRIENT UPTAKE

INTRODUCTION

Disposal of solid wastes ("garbage", "trash", "refuse") is a growing problem for municipal areas. Current methods of disposal have serious limitations. City dumps develop health and water pollution hazards, while burning contributes to air pollution. Carefully designed sanitary landfills can minimize these problems, but it is not always possible to find suitable landfill sites adjacent to cities. In Western Oregon a combination of high winter rainfall, uneven terrain, and generally heavy soils leads to severe limitations in most areas. Few physically suitable sites exist near population centers, and these sites are usually in high demand for other uses.

Ultimately, as landfill sites are filled, other means of waste disposal will be necessary. Some materials, such as metal cans, glass, and newspaper, already can be salvaged and re-cycled; many more may be reclaimed in future. At present the lack of markets and the expense of separating the materials limits re-cycling. Decomposable organic material can be composted and returned to the land as a fertilizer and/or a soil conditioner. Organic wastes can also be pyrolyzed at high temperature and pressure, producing a usable oil with a relatively small resistant residue. This would require a large initial plant investment, but could probably accommodate additional non-municipal waste materials such as straw and wood chips. The residue would then presumably be buried in a landfill.

Another waste disposal alternative, combining minimum sorting and handling with maximum final decomposition and with possible side benefits in land and crop improvement, was investigated in this study. The solid waste, in combination with sewage sludge and septic tank pumpings, was spread on arid land and tilled into the soil. An irrigation system was installed and forage crops were grown on the waste-treated area. The waste material should provide initial wind erosion control and eventually decompose in the surface soil, adding organic matter and releasing plant nutrients. At the same time, the crops would stabilize the soil and provide a productive potential for the area.

This approach combines the idea of waste disposal with the idea of utilizing the waste material, thus deriving a double benefit. Possible drawbacks include any potential health hazard from the exposed waste, potential leaching of contaminants into ground waters, and release of toxic substances into the soil to be taken up by the plants.

This thesis reviews the general pattern of decomposition of the waste materials in the field and focuses on the yield and elemental content of plants grown on the waste-treated soils. Plant problems due to excess micronutrients are identified and the importance of these problems over a period of time is evaluated. Suggestions for successful land application of waste materials are made.

Objectives

1. Observe the general rate of decomposition of solid municipal waste after tillage into sandy soil.
2. Observe changes in soil chemical and physical properties following additions of municipal wastes.
3. Determine the effect of the waste materials on crop yields and plant nutrient content.
4. Identify and evaluate any plant deficiencies or toxicities which appear.

LITERATURE REVIEW

Land Application of Solid Waste

An estimated 250 million tons of solid waste was produced by residential areas in the United States in 1969 (Council on Environmental Quality, 1970). Most of this waste material was deposited in town or city dumps or in sanitary landfills. A great deal was incinerated, or partially burned and then buried in a landfill. Some was dumped at sea, and an "insignificant amount" was composted and used in gardens or greenhouses.

Cities generate large quantities of solid refuse. The American Public Works Association (1966) collected estimates varying from 1100 to 1700 pounds per capita per year produced in 11 major cities across the United States. A twelfth city, San Francisco, reported 800 pounds per capita per year, with the lower figure attributable to a private collection system which based charges on the weight of material collected. Residents were thus encouraged to dispose of as much refuse as possible individually. Methods of collection and and range of materials collected varied from city to city. The refuse was usually reported as combustible or non-conbustible, but occasionally separated as "garbage", "rubbish", "ashes", etc.

The composition of municipal refuse varies considerable with locality, season, method of collection, and subsequent handling. Even so, broad general characterizations made in different areas are in reasonable agreement. The Council on Environmental Quality (1970) estimated that solid waste contains 40 to 50% paper and paper products, with lesser quantities of other organic materials and usually small percentages of inorganic materials such as bottles and cans. There has been a trend toward a larger proportion of paper products as packaging and the use of prepared foods has increased. Ashes, on the other hand, have become a minor refuse component as coal furnaces have been replaced by gas and electric heating systems. Refuse from New York City in 1939 contained an average of 23% paper, 17% garbage, 6% wood and miscellaneous organic materials, 13% metal and glass, and 43% ashes (Rogus, 1964). By contrast, refuse from Chicago in 1956-58 contained an average of 56% paper, 5% garbage, 10% grass, 15% metal and glass, and only 19% ashes.

The percentage of garbage (i. e., food scraps) included in the solid waste varies with the season, the latitude, and the extent of urbanization. City refuse contains more garbage in the summer than in the winter (Rogus, 1964), while in Chandler, Arizona, where fresh produce is available all year, town refuse averaged 43% paper and 22% garbage in 1953 (American Public Works Association, 1966). No ashes were reported in Chandler refuse.

A general estimate of Oregon municipal waste composition lists over 50% paper and paper products, approximately 15% garbage, 10% metals, 10% glass, and smaller amounts of other materials (Advisory Committee on Environmental Science and Technology, Oregon, 1971).

Kaiser (1966) analysed a large number of refuse components for moisture content, ash residue, and calorific value on combustion. He also analysed several of the organic components for carbon, nitrogen, and sulfur content. The carbon content averaged 40 to 60% in all the materials tested, while nitrogen content varied from 0.18% or less in paper to 6% in leather and house dust. Since the latter are minor refuse components while paper is the largest single component, the nitrogen content of a composite waste sample should be very low. Sulfur content ranged from 0.1% in paper and food wastes to about 1% in minor components.

Galler and Partridge (1969) sorted domestic refuse from Raleigh, North Carolina, and Louisville, Kentucky, and compared the nutrient content of food wastes with that of the other combustibles, primarily paper. The carbon content of the two fractions was almost identical, but the nitrogen content of the food was almost ten times that of the paper. Consequently, the C:N ratio of the food wastes was low (15) while that of the paper was very high (over 100). Phosphorus and potassium content was two to eight times higher in the food than in the paper, but the paper contained more sulfur. In general, the food wastes had far greater fertilizer value than the paper.

Very few studies dealing with the application of solid wastes directly to the soil, without prior sorting or processing, have been reported. Hart, Flocker, and York (1970), viewing the problem as one of waste disposal rather than soil or crop improvement, incorporated coarsely ground, unsorted municipal refuse into surface soil at Davis, California, at rates of 50 to 400 tons dry weight per acre. Nitrogen fertilizer was added to balance the C:N ratio of the refuse, and the plots were kept moist, but no plants were grown. After one year, an unidentifiable organic residue plus glass, metal, and plastic remained. There were no odor, insect, or rodent problems, but some blowing of plastic occurred. The second year, it was somewhat difficult to incorporate additional waste material into the soil with 400 tons refuse per acre, since very little soil was mixed with the surface residue.

King, Rudgers, and Webber (1974) applied municipal refuse (0.57%N; 0.08% P) and liquid sewage sludge (0.26% N; 0.14% P) to agricultural soil in Ontario, Canada, at rates of 188 and 376 metric tons dry refuse per hectare (84 and 168 tons/acre) and 2.3 and 4.6 cm sewage per hectare. Totals of 75 kg zinc, 6 kg copper, 37 kg lead, 5 kg chromium, and 0.2 kg cadmium were added to the soil in 188 metric tons of solid refuse; 74 kg zinc, 59 kg copper, 9 kg lead, 24 kg chromium, and 1 kg cadmium were added in 2.3 cm sewage sludge.

The yield and nitrogen content of rye and corn were not significantly affected by the refuse or sewage treatments (King, Rudgers, and Webber, 1974). Copper uptake by the rye increased slightly with sewage treatments, and zinc uptake increased slightly with both materials. Zinc uptake by the corn increased from 54 ppm in control seedlings to 150 ppm in seedlings grown with the heaviest refuse and sewage treatments. No toxicity symptoms were observed. The soil pH was not affected by the refuse or sewage, and soil nitrate levels did not decrease with the addition of refuse. Approximately 80% of the paper in the refuse decomposed by the end of the second year. Decomposition was retarded by low temperatures and saturation of the 15 to 30 cm soil layer where the wastes were concentrated.

Irrigation with hydropulped municipal refuse has also been tested as a potential method of land application (Volk et al., 1973). The hydropulp was prepared by pulping, screening, and partially de-watering solid waste after the removal of inorganic materials magnetically and centrifugally (Herbert and Flower, 1971). The resulting slurry had a pH of 6.3 and a conductivity of 4.5 mmho/cm and contained 1.7% nitrogen, 0.2% phosphorus, 1.7% potassium, and 14.7% sodium (Volk et al., 1973). Irrigation with slurry dilutions of from 1:4 to 1:32 depressed the growth of sorghum seedlings in a growth chamber. Manganese deficiency systems appeared on plants grown in slurry-treated rock soil, and an unidentified tip burn on plants grown in slurry-treated muck soil. Sorghum growth improved when the irrigated soil was re-mixed and re-planted, however. The initial toxic effect of the slurry was not attributed to salt injury, since higher soil salt levels were reached with fertilization than with the waste slurry.

The irrigation procedure deposited the solid waste slurry on the soil surface, where a visible layer was observed. High salt concentrations at the surface could injure seedlings, whereas mixing the soil would distribute the salts and avoid toxic concentrations near the plant roots. An excess of boron in the slurry could also explain the distinctive tip and margin burn described by the authors. Boron levels were not reported in this article.

A great deal of work has been done recently on the potential use of composted municipal refuse on agricultural land. Composting reduces the C:N ratio of the refuse, stabilizes the materials, and eliminates the health hazards associated with fresh refuse. If the compost includes sewage sludge, it usually contains small but significant amounts of nitrogen and phosphorous, which stimulate plant growth. On the other hand, composting may concentrate trace elements to hazardous levels, and excess heavy metals may be added in the sewage sludge.

Fuller, Johnson, and Sposito (1960) reported increased growth of tomatoes and cotton on soil treated with Sacramento municipal refuse compost (0.9% N; 0.6% P) at rates of 2 and 10 tons/acre, with or without additional fertilizer. Yields increased by about 20% on a Mohave clay loam, but only slightly on a Mohave sandy loam. Nitrogen and phosphorous were immobilized by the compost during the first few weeks, then mineralized at sufficient rates to maintain plant growth. Two tons of compost supplied the equivalent of 40 lb nitrogen. Phosphorus uptake by the plants increased with compost additions; most of the additional phosphorus came from the compost rather than from ratioactive-P labeled fertilizer.

Hortenstine and Rothwell (1969) reported increased yields of oats, millet, turnip, and radish with applications of composted refuse from Largo, Florida (2.0% N; 0.3% P), at rates up to 512 metric tons/hectare (228 tons/acre). Nitrogen, phosphorus, and potassium uptake also increased with compost additions. Plants grown with little or no compost were nitrogen deficient, while turnips grown with 512 metric tons compost developed unidentified toxicity symptoms. No toxicity symptoms were observed on turnips grown with 128 metric tons compost, or on any of the other crops. The addition of 128 or 512 metric tons compost/hectare increased the soil pH, CEC, water holding capacity, and content of soluble salts, phosphorus, potassium, calcium, and magnesium. All the soil changes were regarded as beneficial except for the increased salt concentration.

Seed germination was depressed by water extracts of the composted refuse at concentrations of 16, 32, or 64% by weight, depending on the plant species (Hortenstine and Rothwell, 1969). The conductivity of these extracts exceeded 10 mmho/cm and increased with compost rate, so salt tolerance seemed to be the critical factor. Hunt, Hortenstine, and Eno (1973), using saturation extracts of refuse compost - fine sand mixtures, concluded that seed germination should not be affected by compost at rates of 5 or 10% by weight. At higher compost rates, salt concentration and/or the presence of organic toxins could inhibit germination.

Rothwell and Hortenstine (1969) compared the rates of microbial population increase, carbon dioxide evolution, and nitrification of incubated refuse compost, sewage sludge, cow manure, and chicken manure, each mixed with fine sand. The bacterial population multiplied rapidly within the first few days, then decreased rapidly to a steady level. The fungal population increased, leveled off, then began a second slow, steady increase after 15 to 20 days. Carbon dioxide evolution increased linearly with all the organic materials, but the rate of increase was greatest with the materials highest in nitrogen (sewage sludge and chicken manure). Very little nitrification was measured with the composted refuse; when refuse was mixed with the other materials, nitrification was reduced by the refuse.

Hunt, Hortenstine, and Smart (1973) found that parasitic spiral nematodes increased with mineral fertilization of oats and sorghum on fine sand, but decreased significantly with the application of 8 to 32 metric tons of refuse compost per hectare (3.6 to 14 tons/acre). Parasitic ring nematodes were not affected by the compost, and saprophagous nematodes were increased, but only after the second yearly application of compost. Hunt, Smart, and Eno (1973) induced a rapid loss of motility in sting nematodes with water extracts from composted refuse. The extracts were concentrated to approximate refuse applications of 55 to 100 metric tons/hectare (25 to 45 tons/acre). Similar results have also been reported with smaller amounts of organic soil amendments such as alfalfa meal and rice straw.

Pelletized municipal refuse compost from Altoona, Pennsylvania (2.3% N; 0.4% P; 8 ppm Mn; 294 ppm Zn; 16 ppm B; 200 ppm soluble salts) at rates of up to 64 metric tons/hectare (29 tons/acre) increased yields of sorghum grown on sandy soil (Hortenstine and Rothwell, 1973). The pelletized refuse was easier to handle than loose, moist compost, and had a favorable C:N ratio of about 16.

Plant uptake of boron, manganese, and zinc increased only slightly with refuse application, and no salt injury or nutrient toxicity was observed. Soil organic matter content, CEC, and moisture retention were increased slightly by the pelletized refuse.

Woods (1973) applied coarse refuse-sludge compost to sandy forest soil near Gainesville, Florida at rates of 50, 100, and 200 tons/acre. Slash pine seedlings planted five months later survived and grew rapidly on the compost treated soil. Ten-inch seedlings reached heights of 30 inches in seven months with 100 tons compost/acre, compared to 16 inches on the untreated soil. Tree height was slightly less (25 inches) with 200 tons compost/acre, due to shading from weeds. No toxicities were observed, and soil iron, manganese, copper, and zinc levels were not affected by the compost.

Bengston and Cornette (1973), however, reported that the height growth of 3-year-old slash pine was not affected by the application of 44 metric tons/hectare (20 tons/acre) of Gainesville refuse compost to a deep sand soil. The compost used was low in major nutrients (0.5% N; 0.15% P; 0.14% K) but relatively high in trace metals (500 ppm Zn; 200 ppm Cu; 300 ppm Mn; 100 ppm Cd). The nitrogen content of foliage was reduced by the compost during the first year, but no other detrimental effects were observed. The soil pH, organic matter content, CEC, and available phosphorus, potassium, calcium, and magnesium content were increased by the compost.

Terman, Soileau, and Allen (1973), using refuse compost from Johnson City, Tennessee (1.3% N; 0.3% P; 1.0% K; 4.6% Ca; 1500 ppm Zn) at application rates varying from 9 to 286 metric tons/hectare (4 to 128 tons/acre), reported yield increases and increased zinc uptake by tall fescue, corn, and snap beans. Yield increases with refuse compost were less than with equivalent levels of mineral (NPK) fertilizer. Zinc uptake did not reach hazardous levels. Zinc availability was partially held in balance by the liming effect of the compost: addition of sulfur doubled zinc uptake from compost treated soil, while liming untreated soil to the pH of the treated soil (without sulfur) decreased zinc uptake. The authors concluded that a potential hazard remained, since leaching would render compost treated soil more acid with time. The very high zinc content of this compost was due to the sewage sludge added during the composting process rather than to the solid waste, however. Lesser amounts of sludge would reduce the problem and permit less hazardous disposal of the solid waste.

Mays, Terman, and Duggan (1973), using similar refuse compost at rates of up to 327 metric tons/hectare (146 tons/acre), reported that zinc uptake by sorghum doubled with the highest compost treatment. The extractable soil zinc content increased dramatically, reaching 490 kg/hectare with 327 metric tons of compost. No plant toxicity symptoms were observed, however, and yields increased with compost additions. Application of 82 metric tons of compost provided yields equivalent to those produced with 90 kg nitrogen.

Duggan (1973) summarized the results of field demonstrations using the Johnson City refuse compost. He recommended application rates of 15 to 40 tons compost/acre for tobacco and 15 to 30 tons/acre for small grain, but noted that large applications of immature compost with a C:N ratio greater than 30:1 could produce a nitrogen deficiency in young plants. The greatest yield responses to compost additions were obtained on heavy clays or disturbed soils, due to improved soil structure and physical condition. Mulching with refuse compost was comparable to the use of other mulches in weed and erosion control.

In Edinburgh, Scotland, Purves and MacKenzie (1970) noted that soil from urban gardens contained twice as much boron and several times as much copper and zinc as did rural soil, and that these increases were associated with increased uptake of these elements by cabbages. Purves (1972) found levels of 4 to 34 ppm B, 80 to 300 ppm Cu, and 400 to 800 ppm Zn in municipal refuse composts from Edinburgh and nearby towns. He noted that plant toxicity was possible when soil boron content exceeded 3 ppm or when extractable soil copper or zinc exceeded 30 or 200 ppm, respectively.

In a series of field trials using refuse compost at rates of 50 and 100 tonnes/hectare (125 and 250 tons/acre), Purves and MacKenzie (1973) reported that composts containing high levels of boron, copper, and zinc increased the soil content of these elements but had no toxic effect on cabbages, lettuce, potatoes, or peas. The compost increased yields of potatoes and peas due to enhanced soil moisture retention in a dry year. Beans grown with compost containing 100 ppm B developed severe boron toxicity symptoms, however. Leaching the compost prior to application reduced its boron content by one third, and also reduced the boron content of treated soil and plant uptake from treated soil by about one third compared to that obtained with treatments of unleached compost (Purves and MacKenzie, 1974). Copper levels in the compost were unaffected by the leaching, and zinc content was reduced in only one case. Bean germination was reduced more severely with the unleached compost than with the leached compost. Boron toxicity symtoms appeared on beans grown with the unleached compost, while beans grown with leached compost remained healthy.

In general, equivalent yield increases can be obtained more cheaply with mineral fertilizer than with the use of solid waste or refuse compost. On poor soils, however, refuse compost can improve soil structure and moisture retention and thus contribute indirectly to crop yields. Disposal of composted solid waste on agricultural land appears feasible within certain limitations: the nutrient content, particularly the nitrogen content, of the compost must be balanced with fertilizer; and the trace elements added in the compost must not exceed plant tolerances. Rates of refuse compost application must therefore be determined with respect to particular localities (since refuse composition varies) and to particular crops.

An alternate and potentially valuable use of refuse or refuse compost is in the reclamation of soil material which is presently unsuitable for any type of agriculture or, often, any type of vegetation at all: strip mine spoils, mine tailings, and various industrial deposits. Dobson and Wilson (1963) found that the decomposition rate of fresh household refuse increased when the refuse was mixed with spoil material from two strip mined areas in West Virginia. The low pH (3.7 and 4.4) of the spoils did not affect the decomposition rate, and the refuse contained sufficient micro-organisms for active decomposition without inoculation.

Hortenstine and Rothwell (1972) found that refuse compost applied at 35 and 70 metric tons/hectare (16 and 31 tons/acre) added organic matter and plant nutrients to sand tailings from phosphate mining at Bartow, Florida. Sorghum and oat yields from the treated sand were low compared to normal agricultural yields, but the crops did become established. Yields increased greatly the second year, indicating a build-up of soil fertility. Trace element content did not increase to hazardous levels in either crop.

Scanlon, Duggan, and Bean (1973) applied refuse compost from Johnson City, Tennessee to strip mine spoils in Virginia at rates of 72 and 184 tons/acre, with and without mineral fertilizer and lime. After four years, the pH of the compost treated spoil material had increased from less than 4 to 6 or above, a grass cover had become established, and Virginia pine seed had germinated and grown to heights of 3 to 5 feet. No toxicity symptoms appeared on grass or trees. On the control plots, vegetation had become established only where compost material had been washed from adjacent treated plots and deposited on the bare spoil. On a second spoil area treated with 14 to 26 tons compost/acre, a grass-lespedeza cover was significantly greater than on the bare spoil after two years, but the spoil pH had increased only slightly and very little organic material remained.

Terman, Soileau, and Allen (1973) reported that Johnson City refuse compost applied at 45 and 90 metric tons/hectare (20 and 40 tons/acre) raised the pH of acid eroded Copper Basin soil material from 4.1 to 6.1 in five months. Fescue growth increased with the compost treatments; zinc uptake by the fescue also increased, but did not reach toxic levels.

Duggan and Scanlon (1974) used Johnson City compost at rates of 50 and 100 tons/acre to reclaim an alkaline abandoned ash pond (a former ash disposal site for a coal-fired steam electricity plant) which was almost devoid of vegetation. Survival and growth of fescue and white clover were greatest with 100 tons compost/acre, with or without mineral fertilizer. Direct seeding of tree species was unsuccessful, but 77 and 85% survival of Virginia pine and European black alder seedlings, respectively, was observed after two years. Tree growth was greatest with the highest compost rate. No toxicities from the compost or the ash were observed.

The use of refuse compost on barren lands made re-vegetation possible in these cases. Soil stabilization and the addition of organic matter permitted the establishment of a cover crop where fertilization alone failed. Crop yields were generally small but could be expected to increase with time. Toxic concentrations of trace metals were not evident, even with high rates of compost application. In addition, of course, the solid waste decomposed. The problem of waste disposal could conceivably be solved if the value of the land reclaimed should exceed the cost of handling and transporting the waste material.

Land Application of Treated Sewage

Treated sewage has long been used as an alternate to manure for the fertilization of truck crops at experimental centers near large European and English cities (Rohde, 1962; Patterson, 1971;

Le Riche, 1968). Significant yield increases were usually obtained with sewage sludge, but no direct comparisons were made between sewage sludge and mineral fertilizers.

In the United States, chemical fertilizers have generally replaced the use of manures or other organic amendments in agriculture. Recently, however, concern over water pollution in some areas and a lack of sufficient water in others has led to a reappraisal of the value of land disposal of sewage sludge. Aside from the value of sewage disposal _per se_, the sludge can contribute significant amounts of nitrogen, phosphorus, and potassium for use in crop production. Kardos (1970) found that irrigation with one inch of liquid sewage effluent per week from April to November provided the equivalent of 1150 kg/ha (1025 lb/acre) of a 14-15-14 NPK fertilizer, and doubled yields of corn, oats, and alfalfa hay over those produced with the usual fertilizer rates. King and Morris (1972a) reported that a total application of 242 metric tons of sewage sludge per hectare (108 tons/acre) over a two-year period produced yields of Bermuda grass equivalent to those produced with 358, 112, and 224 kg/ha of nitrogen, phosphorus, and potassium, respectively.

In Arizona, irrigation with municipal wastewater produced slightly greater wheat yields than did irrigation with well water plus nitrogen, phosphorus, and potassium fertilizer equal to the nitrogen, phosphorus, and potassium content of the wastewater: 224, 73, and 140 kg/ha, respectively (Day et al., 1974). The dry yield of oat forage also increased slightly, but there was no difference in grain yield or total protein produced (Day and Kirkpatrick, 1973). Irrigation with wastewater over a period of 14 years produced the same yields as irrigation with well water plus fertilizer with a cotton-sorghum-barley rotation, and increased soil levels of nitrate, phosphorus, and soluble salts (Day, Stroehlein, and Tucker, 1972). Soil organic matter content decreased slightly, possibly due to greater microbial activity.

Pratt (1973) measured the nitrogen mineralization rate of sewage sludge (2.5% N) and various animal manures. He calculated the yearly mineralization rates to be expected from constant additions of each waste material, and also the yearly additions necessary to maintain a constant mineralization rate per year, according to a mathematic decay series for each material.

The addition of liquid sewage sludge can have detrimental side effects, however. A surface crust which restricts soil infiltration may form as the sludge dries, unless it is tilled into the soil (Thomas, Schwartz, and Bendixen, 1966).

Lunt (1959) reported that seed germination was delayed by the application of ten tons of sewage sludge per acre, due to high salt concentrations. Fresh anaerobic digested sludge can also be toxic to seedlings (Molina et al., 1971), but aging the sludge for one week in contact with air before use removed the toxic effect. The initial toxicity appeared to be due to a combination of factors, including excess ammonium concentration, salts, and oxygen deficiency.

Sewage sludge also adds variable quantities of micronutrients and trace metals to the soil. The micronutrients may benefit crops grown on otherwise deficient soils, but in excessive concentrations they may be detrimental to plant growth. Rehling and Truog (1940) found that extracts of Milorganite (a sewage sludge compost produced in Milwaukee) containing 36, 344, 194, and 241 ppm available boron, copper, manganese, and zinc, respectively, caused the resumption of normal growth in deficient corn seedlings. The extracts also produced increases in dry yield and uptake of these elements by tomato and sunflower seedlings, compared to yield and uptake from untreated cultures. However, increased industrialization has led to an increase in the heavy metal concentration of sewage sludges in many areas. Berrow (1972) reported the average levels of trace elements in sewage sludges, including ranges of 1000 to 5000 ppm Zn, 100 to 1000 ppm Mn and Cu, 50 to 500 ppm Cr, 10 to 100 ppm B, 1 to 100 ppm Co, and 1 to 10 ppm Mo. Sludges from particular localities may greatly exceed these ranges in one or more trace elements, indicating local sources of industrial contamination.

Toxic accumulations of heavy metals, notably copper and zinc, in soils after extended use of sewage sludge have been reported in Europe and England. At the Berlin and Paris "sewage farms", where sludge had been used as fertilizer for 50 to 80 years, Rohde (1962) found higher copper and zinc levels in the soil under unhealthy plants than in soil under healthy plants, and concluded that excess copper and zinc were responsible for the plant problems. At Cambridge, England, Patterson (1971) reported severe damage to vegetables grown on soil which had received 45 metric tons sewage sludge per hectare (20 tons/acre) annually for 30 years. Accumulations of 5000 ppm Zn, 500 ppm Cu, 1500 ppm Pb, 150 ppm Cr, and 50 ppm Ni were measured in the surface soil.

On the other hand, the accumulation of heavy metals from sewage sludge does not necessarily become toxic with reasonably long periods of use, and may not be completely irreversible. Le Riche (1968), at the Woburn, England, market-garden experiment station, observed no toxicity symptoms in vegetables grown on soil treated with an average of 66 metric tons sewage sludge per hectare (29 tons/acre) for 19 years. There was a substantial increase in the soil content of copper, zinc, nickel, lead, and chromium, however, and the zinc and nickel content of the vegetables was higher than normal. Some, but not all, of the vegetables also contained more copper, chromium, or molybdenum than normal. The sewage treatments were discontinued, and six years later some reduction in the soil content of zinc, nickel, and lead had occurred: i.e., the zinc level decreased from 395 ppm in 1959, after a total of 1260 metric tons sewage/hectare (562 tons/acre) had been applied, to 275 ppm in 1967.

In Sweden, using the much lower rate of 105 metric tons sewage sludge per hectare (47 tons/acre) applied over a period of 12 years, Andersson and Nilsson (1972) found increases of from 50 to 300% in the zinc, copper, nickel, chromium, lead, and selenium content of sludge treated soil; lesser increases in boron, molybdenum, cadmium, and arsenic; and no significant difference in manganese or cobalt. No plant toxicities were observed, although zinc and copper levels reached 369 and 70 ppm, respectively, in the sludge treated soil. The soil content of mercury increased at an alarming rate (from 0.018 to 0.675 ppm) with the sludge treatments.

The percent recovery of these elements from the surface 20 cm of soil after 12 years of sludge treatments was 100% or more except in the case of boron (Andersson and Nilsson, 1972). Boron recovery was only 49%, due to leaching losses. Recovery rates appreciably greater than 100% (170% recovery of mercury; 146% recovery of zinc and chromium; 140% recovery of nickel) lead one to wonder whether the metals recovered did in fact come from the sewage sludge, or whether other sources of contamination were involved. Purves (1972) found that the zinc and copper content of urban soil was many times that of rural soil; it is possible that metals from urban or industrial dust had accumulated on the Swedish soil as well.

In the United States, Hinesly, Braids, and Molina (1971) and Hinesly, Jones, and Ziegler (1972) reported large increases in soil manganese, copper, zinc, chromium, nickel, and cadmium content after liquid sewage sludge from Chicago was applied at rates of 10 and 5 inches/year for three years. With 10 inches/year, the sludge supplied 44 kg Mn, 132 kg Cu, and 510 kg Zn per hectare per year and increased soil manganese content from 122 to 306 ppm, soil copper content from 17 to 352 ppm, and soil zinc content from 459 to 2175 ppm. Manganese uptake by field crops increased but did not reach toxic levels; copper uptake was not affected. Zinc uptake reached very high levels (1200 ppm in soybean leaves), but zinc uptake from the untreated soil was also high (827 ppm). In this case, the soil already contained excessive amounts of zinc, and the sludge treatments intensified the problem. Even so, soybean yields tripled with the sludge treatments, due primarily to the large quantity of nitrogen added in the sludge: over 3000 lb/acre per year, compared to fertilizer applications of 200 lb N/acre on the untreated soil. The yield response and zinc uptake of corn, sorghum, and canary grass were less pronounced, and no toxicities were observed.

King and Morris (1972a; 1972b) also reported increased zinc uptake following sewage sludge treatments of up to 242 metric tons/hectare (108 tons/acre) over a two-year period, which contributed up to 612 kg Zn and 116 kg Cu per hectare to the soil. The zinc content of Bermuda grass increased to 340 ppm, but no toxic effect was observed; yields were greater than or equal to those obtained with NPK fertilizer. The zinc content of rye increased with sludge additions, but yield was not affected by sludge rates of 42, 84, or 121 metric tons/hectare. With the addition of 242 metric tons sludge per hectare, however, yields of rye were drastically reduced and zinc uptake reached toxic levels (580 to 775 ppm). Uptake of copper, manganese, and boron increased only slightly with this treatment. Liming the soil decreased the uptake of manganese, copper, and zinc and reduced the toxic effect of the sludge.

Page (1973) reviewed most of the work cited here and estimated the quantities of 17 trace elements added to the soil in 100 metric tons (90 tons) of a "typical domestic sewage sludge". From this data, combined with estimates of the range of each element in soil, he calculated the rate of sludge application which would exceed the ability of the soil to adsorb each element. Boron, cadmium, copper, and zinc appeared to present the greatest hazard in heavy sludge treatments. The hazard of boron toxicity was greatly over-estimated, however, since much of the boron applied in sludge is usually leached from the soil profile. If rates were adjusted within the tolerance limits for copper, zinc, and cadmium, sewage sludge could safely be applied to agricultural land.

Strictly in terms of fertilizer value, the land application of sewage sludge is not economically profitable (Carlson and Menzies, 1971). As a method of ultimate disposal, however, it is becoming increasingly attractive; the risks are few if rates of application are not excessive.

In addition to waste disposal, benefits in terms of water use may result from the land application of sewage effluent. In Arizona, for example, wastewater replaced irrigation water (Day, 1973), which can be expensive in dry areas. In Pennsylvania, the application of liquid sewage effluent to agricultural and forest land proved to be an effective means of restoring ground water and avoiding stream pollution (Kardos, 1970). With effluent rates of up to four inches per week on forest soil, 98% of the phosphorus in the effluent was removed by the first foot of soil during the first year, and 86% during the second year.

Nitrate levels in the percolation water were very low (less than 0.5 mg NO_3-N/1) with effluent rates of one or two inches per week, but reached 10 mg NO_3-N/1 (the U.S. Public Health Service limit for potable water) with four inches sewage per week. The latter rate was sufficient to saturate the soil for varying periods during the year. Water purification was excellent: very few coliform bacteria were recovered from percolation water at depths of two or four feet. A boron toxicity developed in red pine growing on saturated soil, however. Boron was added at the rate of 4 lb/acre annually with the application of four inches sewage per week, and this rate exceeded the boron tolerance of red pine unless leaching occurred.

On cropland, 49% or more of the phosphorous added in sewage effluent applied at one inch per week from April to November of each year was removed with clover hay, and 22% of the phosphorous added at an effluent rate of two inches per week was removed with corn silage (Kardos, 1970). Nitrogen removal varied from 60 to 130% with corn or wheat grain, and from 105 to 200% with corn silage, indicating crop use of soil nitrogen as well as nitrogen from the sewage. Nitrate levels in percolating water were reduced to less than 3 mg NO_3-N/1.

Sewage sludge and sewage effluent have also been used effectively for strip mine reclamation. Sopper (1972) applied liquid sludge and effluent, separately and in combination, at rates of one or two inches/week to spoil material from a Pennsylvania strip mine which had been barren since 1945. Tree seedlings were planted and grass, clover, and vetch seed was broadcast on the treated soil. After two years of continuous sewage treatment, no vegetation had survived on the untreated spoil, whereas a ground cover of 30 to 100% had become established on the sewage treated spoil and tree survival was generally good (60 to 100% with some species). The greatest tree growth was obtained with 1 in/wk effluent plus 1 in/wk sludge; the greatest forage growth, with 2 in/wk effluent plus 2 in/wk sludge. The high acidity of the spoil material seemed to be the limiting factor: spoil pH was raised from an average of 2.5 to an average of 4.6 by the latter treatment, within the first year.

Sutton and Vimmerstedt (1974) established a grass-clover ground cover on spoil banks in southeastern Ohio with a single heavy application of sewage sludge containing 1.8% N, 1.3% P, and 0.38% K. Application of 294 tons sludge per acre raised the spoil pH from 2.3 to 5.8 and produced a heavy stand of forage. By comparison, application of 87 tons lime per acre plus NPK fertilizer also raised the spoil pH to 5.8 and produced some forage growth, but much less than the sludge. The sewage sludge proved highly effective against runoff and erosion of the sloping spoil bank. Forage harvested from the sludge treated spoil was high in manganese and aluminum, however, and could be detrimental to livestock.

Hinesly, Jones, and Sosewitz (1972) strongly recommended the use of sewage sludge on strip mine spoils in Illinois, where the spoil material is usually neither acid nor very stony. They note that excellent yields of legumes and fair yields of wheat and rye have been produced on sludge treated spoils, and predict that the mined land could be returned to crops such as corn and soybeans after improvement by sludge treatments and forage cropping. They also observe that many trace elements in the sludge are irreversibly adsorbed by spoil materials, so that higher loading rates can be tolerated on spoils than on agricultural land.

MATERIALS AND METHODS

Waste Materials

Solid waste was obtained from the Vancouver, Washington, municipal landfill site. Both household and commercial refuse, including such heterogenous materials as garbage, tree and lawn trimmings, appliances, tires, metal and glass containers, and a large proportion of paper and plastic packaging materials, are brought to this landfill. Large items such as appliances are handled separately at the landfill site; all smaller materials are put through an industrial grinder before being compacted and buried. The grinder compacts or tears paper and cardboard into pieces ranging up to about 12 inches in diameter. Cloth is generally compacted rather than torn. Wood is usually broken up well, but occasional large pieces (sticks 1 to 2 inches across and 12 inches or more in length) come through the grinder. Food products are not recognizable after the grinding; they are apparently blended and absorbed by the paper. Glass is shattered; most emerges as sand-sized grains, with some larger pieces up to about one-half inch. Metal cans are crushed into small balls. Brittle plastics are broken up well, but soft plastics and rubber often come through in rather large pieces. Tennis shoes, for example, emerge weather-beaten but more or less intact.

This heterogenous mixture of refuse, without further treatment, was trucked to the experimental site 160 miles east of Portland, near Boardman, Oregon. The shredded waste was stockpiled for several days prior to land application.

A mixture of sewage sludge and septic tank pumpings was obtained from the Lake Oswego treatment plant serving the Portland, Oregon, municipal area. The sludge had been digested anaerobically, chlorinated, and thickened. When released for land application, the mixture was a brownish-black liquid with about two percent suspended solids and a mild offensive odor.

Field Experimental Plots

Field plots were established ten miles southeast of Boardman, in Morrow County, north central Oregon, on land leased by the State of Oregon to The Boeing Company. The area is part of the Columbia Basin, an arid region 600 ft. above sea level and 350 ft. above the Columbia River, formed from old lake beds overlain by wind-deposited fine sand. The land is nearly level, with a ground cover of bunch grasses and scattered brush. The predominant soil series is Sagehill sand, a loamy fine sand overlying a silt loam (Appendix I). There is a weakly cemented caliche layer at a depth of three to four feet. The soil is moderately alkaline, has a cation exchange capacity of 8 to 9 me/100g, and an organic matter content of 0.5%.

Solid municipal waste was spread on 20 ft. by 120 ft. plots in September 1971 at application rates of 0, 100, 200 and 400 tons per acre (dry rates of approximately 0, 67, 133, and 267 tons per acre). Each treatment was replicated three times. Sewage was applied at the rate of 55 gallons per ton of solid waste. One plot received solid waste only, at the 400 ton/acre rate, due to a miscalculation in the amount of sewage hauled to the test site.

When the wastes were spread and compacted they formed layers approximately two, four, and eight inches thick on the plots with 100, 200, and 400 tons solid waste per acre. All plots were rototilled to an eight-inch depth, then re-compacted. Nitrogen fertilizer was applied in the form of ammonium sulfate.

The entire experimental area was seeded with Hyslop semi-dwarf winter wheat in October 1971. Wheat was planted initially because it was too late in the season to establish a forage crop, yet a cover crop was needed to prevent wind erosion during the winter months.

In April 1972 the wheat was rototilled down, prior to planting fescue and alfalfa. The plots which received 400 tons solid waste per acre were plowed prior to rototilling. This operation succeeded in mixing the waste material fairly well with the soil, thus improving seedbed conditions. Phosphorus and zinc fertilizers were rototilled into the soil at the same time. The entire experimental area received 220 lb. phosphorus per acre (as triple superphosphate) and 10 lb. zinc per acre (as zinc sulfate). Sulfur fertilizer was also recommended for the area, but was more than adequately supplied by the ammonium sulfate.

Each municipal waste plot was seeded to Fawn fescue and to Sernac alfalfa, in a split-plot design which included a nitrogen variable (Table 1, Figure 1). The final treatment plot size was 10 ft. by 40 ft. The alfalfa seed was inoculated just before planting. The aisles and borders were seeded with Fawn fescue.

Nitrogen was applied in split applications at about four-week intervals (two-week intervals for the highest treatment), beginning in April 1972 at the time of the spring planting (Table 2). On the alfalfa plots, the spring applications were reduced and no nitrogen was applied after May 1972.

A solid-set sprinkler irrigation system was provided and operated by The Boeing Company. Water was drawn from a well located at the test site. The plots were irrigated for approximately two hours daily during the growing season. Rates of irrigation were scheduled to meet consumptive use plus an additional 15 to 20% to allow for distribution irregularities. The irrigation system was in operation until frost occurred in the fall of 1971 and from about

Table 1. Municipal waste and nitrogen treatments.[1]

Solid waste[2] ton/acre	Sewage gal/acre	Nitrogen[3] lb/acre	
		Alfalfa	Fescue
0	0	80	250
0	0	200	500
0	0	400	1000
100	5500	200	500
100	5500	400	1000
100	5500	600	2000
200	11000	200	500
200	11000	400	1000
200	11000	600	2000
400	22000	200	500
400	22000	400	1000
400	22000	600	2000

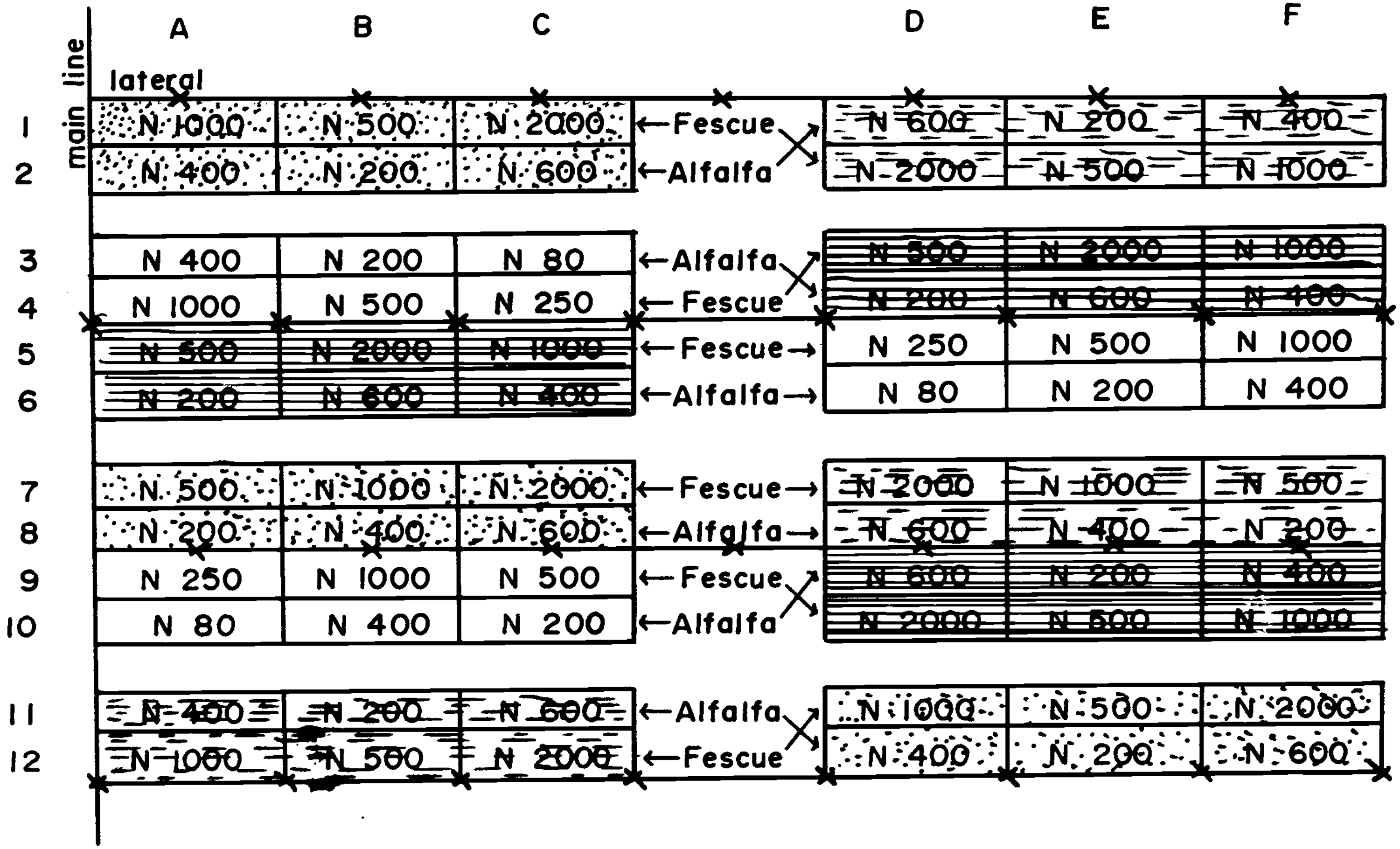
[1] Each treatment replicated three times.

[2] Approximately 33% moisture.

[3] Applied as ammonium sulfate.

mid-May until mid-September in 1972.

The alfalfa and fescue were harvested on June 29, August 3, and September 10, 1972. At each harvest a 3-foot strip down the center of each plot was cut and weighed. Plant samples were collected for moisture determinations and subsequent dry yield per acre calculations. After the yield data had been recorded the entire plot area was mowed and raked.



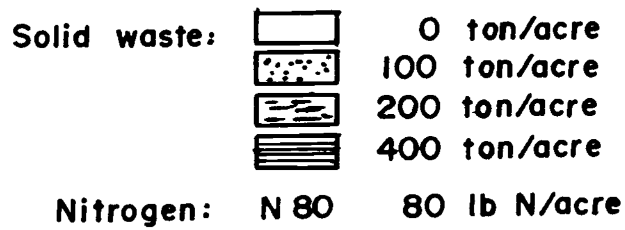


Figure 1. Field plot design.

Table 2. Nitrogen applications to field plots, 1971-1972.

Total nitrogen[1] lb/acre	Nitrogen applied October 1971 lb/acre	Nitrogen applied in 1972, by dates of application 4/19	5/9	5/19	6/2	6/22	6/30	7/13	8/2	9/22
		lb/acre								
	Wheat	Fescue								
250	80	50	20	-	50	-	50	-	-	-
500	130	100	70	-	100	-	100	-	-	-
1000	180	160	60	-	200	-	200	-	-	200
2000	280	170	150	200	200	200	200	200	200	200
	Wheat	Alfalfa								
80	80	-	-	-	-	-	-	-	-	-
200	130	70	-	-	-	-	-	-	-	-
400	180	110	60	50	-	-	-	-	-	-
600	280	160	110	50	-	-	-	-	-	-

[1] Applied as ammonium sulfate.

Wheat samples for elemental analysis were collected from each plot in April 1972; alfalfa and fescue samples, in June and September 1972. Surface soil samples were collected from all plots in April, June, and September 1972. In addition, soil profile samples were collected by bucket auger from check plots and from plots with the highest waste treatment. Soil samples were collected to a depth of 60 inches in April, but only to 24 inches in June and 36 inches in September.

The fescue plots were rototilled and re-seeded to Fawn fescue in the spring of 1973, after severe winter frost damage. The alfalfa was not damaged by frost, so the established stands were retained.

Nitrogen fertilizer treatments to the fescue were reduced in 1973 (Table 3). No further fertilizer was applied to the alfalfa.

Three cuttings of alfalfa were harvested in 1973: on May 31, July 11, and August 22. Yields were measured and the plots were mowed as during the previous year. There was insufficient growth on the newly planted fescue plots to make a cutting in May, but these plots were harvested as usual in July and August. Alfalfa samples were collected in May and August; fescue samples, in July only. Surface soil samples were collected from all plots in March and September 1973. Soil profile samples were collected to a depth of 60 inches from one check plot and two plots with the highest waste treatment in both March and September 1973.

Table 3. Nitrogen applications to fescue plots, 1973.

Plot identification	Nitrogen applied[1], by dates 5/31	6/30	8/22
	----------- lb/acre	---------	
Check			
N 250[2]	50	50	50
N 500	100	100	100
N 1000	200	200	200
Waste treated			
N 500	50	50	50
N 1000	100	100	100
N 2000	200	200	200

[1] Applied as ammonium sulfate.

[2] Nitrogen applied in 1971-1972, lb/acre.

Additional surface soil samples were collected in March 1973 for microbial population estimates. One composite sample was obtained by mixing ten sub-samples taken at 1.5 foot intervals along a transect across an undisturbed area adjacent to the plots. A second composite sample contained sub-samples from each of six check plots. Finally, a composite sample was obtained from six plots which received 400 tons solid waste per acre.

Greenhouse Experiments

A preliminary greenhouse experiment was conducted during the winter of 1971-72 to assay any major plant problems prior to the first growing season at the field site. The Sagehill soil used in the greenhouse study was collected from an area adjacent to the field plots. Solid waste and sewage materials were obtained from the Vancouver landfill site and the Lake Oswego sewage treatment plant. The solid waste was hand processed to obtain a more uniform distribution of materials. Paper, plastic, cloth, rubber, and wood were cut into pieces of 2-inch maximum dimensions; very large pieces of material such as tennis shoes and plastic bottles were rejected.

The solid waste and sewage were mixed with soil in pots six inches deep and seven inches in diameter, in proportions similar to those used in the field (Table 4). An eight-inch plow layer was assumed for the calculation of soil:waste ratios. Since the 400 ton solid waste treatment formed an eight-inch surface layer on the field plots, an extra inch of soil was assumed for this treatment, so that a small amount of soil was included in the pot mixture. The bulk density of the solid waste was about 20% of the soil bulk density, so the waste:soil weight ratio of 2.4 for the 400 ton treatment corresponded to a volume ratio of about 12.

Table 4. Waste and nitrogen treatments for wheat growth under greenhouse conditions.

Field equivalent				Greenhouse treatment			
Solid waste ton/acre	Sewage gal/acre	Nitrogen lb/acre	Waste:soil wt/wt	Soil gm/pot	Solid waste gm/pot	Sewage ml/pot	Ammonium sulfate gm/pot
0	0	80	0	4000	0	0	0.655
0	0	130	0	4000	0	0	1.065
0	0	180	0	4000	0	0	1.474
100	5500	130	0.1	2667	267	80	1.065
100	5500	180	0.1	2667	267	80	1.474
100	5500	280	0.1	2667	267	80	2.293
200	11000	130	0.3	1600	480	160	1.065
200	11000	180	0.3	1600	480	160	1.474
200	11000	280	0.3	1600	480	160	2.293
300	16500	130	0.9	727	655	240	1.065
300	16500	180	0.9	727	655	240	1.474
300	16500	280	0.9	727	655	240	2.293
400	22000	130	2.4	308	738	320	1.065
400	22000	180	2.4	308	738	320	1.474
400	22000	280	2.4	308	738	320	2.293
100	0	130	0.1	2667	267	0	1.065
100	0	180	0.1	2667	267	0	1.474
100	0	280	0.1	2667	267	0	2.293
0	5500	0	0	4000	0	80	0
0	5500	180	0	4000	0	80	1.474
0	22000	0	0	4000	0	320	0
180[1]	15000	130	0.1	4000	430[1]	220	1.065

[1] Metal sorted from the solid waste.

Nitrogen fertilizer as ammonium sulfate was added in amounts corresponding to the initial field fertilization of 80, 130, 180, and 280 lb N/acre. All treatments were carried out in duplicate.

In addition to the basic treatments, mixtures of soil with solid waste only and of soil with sewage only were assayed. Finally, one pot received soil and pieces of metal sorted from the solid waste (Table 4).

All pots were planted on January 25, 1972, with 40 Hyslop winter wheat seeds per pot. The pots were placed in a greenhouse with temperature maintained at 75^{o}F and day length at 16 hours. They were watered immediately after planting and then periodically as needed. Germination counts were made after ten days. Plant height and yield were measured after three weeks, and the plants were dried and ground for elemental analysis.

A second greenhouse experiment was conducted during the summer of 1972 to diagnose the cause of the tip burn observed in the first experiment and to observe the response of forage crops to the waste additions. Four crops were planted: Hyslop winter wheat, to confirm the previous observations; Fawn fescue and Sernac alfalfa, forage crops planted in the field; and Blue Lake beans, a crop which exhibits clear symptoms of several nutrient deficiencies and toxicities. Solid waste and sewage treatments similar to the field experiment were used, with an additional lower treatment of 50 tons solid waste per acre. The waste:soil ratios used in the first greenhouse experiment were retained, but the quantities were increased somewhat to provide a larger rooting volume (Table 5). Nitrogen was applied as ammonium sulfate in split applications spaced over a 10-week growing season. All treatments were carried out in quadruplicate.

The pots were planted on June 10, 1972 with 8 bean seeds or 30 wheat, alfalfa, or fescue seeds per pot (later thinned to half as many plants). Greenhouse temperature and day length were maintained as in the first experiment. The pots were watered with distilled water as needed to maintain moisture contents within a maximum midway between field capacity and saturation, and a minimum slightly above the wilting point.

The beans were harvested on July 10, 1972, then re-planted and harvested again on August 11. The wheat was harvested on July 24; alfalfa, on July 31; and fescue, on August 11. Percent germination, visible plant symptoms, and dry plant yields were recorded.

Sample Preparation and Analysis

Plant samples from the field or greenhouse study were air-dried at room temperature, ground in an Osterizer blender, re-dried in an oven at 70° C, and stored in plastic bags. Each sample

Table 5. Waste and nitrogen treatments for alfalfa, beans, fescue, and wheat.[1]

Field equivalent				Greenhouse treatment		
Solid waste ton/acre	Sewage gal/acre	Nitrogen[2] lb/acre	Waste:soil wt/wt	Soil gm/pot	Solid waste gm/pot	Sewage ml/pot
		Alfalfa				
0	0	50	0	4000	0	0
0	0	200	0.	4000	0	0
50	2750	200	0.04	3620	160	40
50	2750	600	0.04	3620	160	40
100	5500	200	0.1	3200	320	80
100	5500	600	0.1	3200	320	80
200	11000	200	0.3	1920	580	160
200	11000	600	0.3	1920	580	160
400	22000	200	2.4	340	810	320
400	22000	600	2.4	340	810	320
		Beans, fescue, wheat				
0	0	250	0	4000	0	0
0	0	500	0	4000	0	0
50	2750	500	0.04	3620	160	40
50	2750	2000	0.04	3620	160	40
100	5500	500	0.1	3200	320	80
100	5500	2000	0.1	3200	320	80
200	11000	500	0.3	1920	580	160
200	11000	2000	0.3	1920	580	160
400	22000	500	2.4	340	810	320
400	22000	2000	2.4	340	810	320

[1] Each treatment replicated four times.

[2] Applied as ammonium sulfate.

was thoroughly mixed before sub-samples were taken for analysis.

Sub-samples were digested with a nitric acid-perchloric acid procedure routinely used for plant analysis (Jackson, 1958). The digests were assayed directly by atomic absorption for iron, manganese, copper, and zinc. Appropriate dilutions were made for calcium, magnesium, potassium, and sodium determinations. To reduce ion interferences, strontium chloride was added to the dilutions for calcium and magnesium determinations, sodium chloride was added for potassium determinations, and potassium chloride was added for sodium determinations (Perkin-Elmer, 1971).

Aliquots of the nitric-perchloric acid digests were assayed for phosphorus and sulfur contents. A colorimetric procedure was used for phosphorus analysis, with an ammonium molybdate-vanadate complex as the color-producing reagent (Jackson, 1958). Sulfur content was determined turbidimetrically, using barium chloride as the precipitating agent (Black, 1965).

The nitrogen content of the ground plant tissue was determined by a micro-Kjeldahl digestion and steam distillation procedure (Jackson, 1958).

Separate plant digests were prepared for boron, molybdenum, cobalt, and chromium analyses. One-gram samples of the plant material were ashed in a muffle furnace for four hours at 500°C, then dissolved in 20 ml of 1 N hydrochloric acid. The digests were assayed directly by flameless atomic absorption for molybdenum (Henning and Jackson, 1973), cobalt, and chromium. A graphite furnace was used to provide the very high temperatures required for atomization of these elements: 2400^{o}C for cobalt and 2600^{o}C for molybdenum and chromium.

Aliquots of the ash-hydrochloric acid digests were assayed for boron content by a colorimetric procedure, using curcumin as the color-producing reagent (Jackson, 1958; Roberts et al., 1971).

Soil samples were air-dried at room temperature, then ground with a mortar and pestle and passed through a 2 mm sieve. The material retained by the sieve was hand sorted to separate pieces of metal, glass, hard plastic, etc. from organic materials such as paper, cloth, and plastic film. A low-pressure air hose was used to remove the light-weight organic materials. Heavier materials were then separated with a small brush. There was very little gravel in this soil.

The metal, glass, etc. were rejected from the sample; the paper, cloth, and plastic were ground in an Osterizer blender and re-mixed with the material which passed through the sieve. Pieces of wood small enough to be ground in the blender were retained with the paper, while larger pieces were rejected. The ground, mixed samples were stored in plastic containers and re-mixed when sub-sampled for analysis.

Soil pH was measured with a pH meter, using aqueous soil suspensions (25 gm. soil : 50 ml. distilled water) which were allowed to equilibrate for one hour at room temperature before measurement. Conductivity was measured with an electrical conductivity bridge, using the extracts from water-saturated soil pastes.

Water-soluble boron content was determined by a curcumin colorimetric procedure, using aliquots from refluxed water extracts (Jackson, 1958; Roberts et al., 1971).

Extractable sodium content was determined by atomic absorption after extraction with neutral 1 N ammonium acetate. The extract was diluted with a potassium chloride solution to reduce ion interference. Extractable iron, manganese, copper, and zinc were determined by atomic absorption after extraction with diethylenetriamine pentaacetic acid (DTPA) and triethanolamine (Roberts et al., 1971).

Composite soil samples for microbial counts were passed through a 2 mm sieve and stored moist at 3°C. Organic matter content was determined by weight loss on ignition; total nitrogen content by a micro-Kjeldahl procedure (Jackson, 1958); and pH with a pH meter, using a water-saturated soil paste. Microbial counts were made following the procedures of Pramer and Schmidt (1964). Plate counts of bacteria were made on nutrient agar; of fungi, on acid agar. Algae were grown in an inorganic nutrient solution and enumerated statistically.

RESULTS AND DISCUSSION: WASTE ANALYSIS

Elemental Analysis of Municipal Wastes

Both the solid waste and the sewage sludge were analysed for elemental content. A five-pound grab sample of the solid waste was air-dried and separated with two-millimeter and one-millimeter sieves. The material smaller than two millimeters and that smaller than one millimeter were sampled separately for analysis. The fraction retained by the two-millimeter sieve was hand sorted to remove metal, rubber, glass, and large pieces of wood. The remainder (primarily pieces of paper and plastic) was ground in an Osterizer blender and sub-sampled for analysis. Several samples of each fraction of the waste were analysed, with the exception of the large pieces of inert materials. No satisfactory method was found to obtain a representative sample of these materials.

The solid waste was primarily composed of high-carbon materials. The average carbon content of the waste as a whole was 48.5%, as determined by the O.S.U. Soil Testing Laboratory (October 1971). The average nitrogen content was 0.76%, giving a C:N ratio of approximately 64. This may be an under-estimate, since the more detailed analysis found slightly lower nitrogen levels in the solid waste components (Table 6). In either case, the C:N

Table 6. Elemental analysis of solid waste.

Fraction	Percent of total	N	P	S	Ca	Mg	K	Na
		% dry weight						
Solid waste >2 mm.[1]	76	0.65	0.16	1.6	1.99	0.11	0.26	0.28
(organic material)		0.63	0.15	1.6	2.03	0.11	0.26	0.25
			0.16	1.4	1.95	0.12	0.22	0.22
			0.17	1.6	1.90	0.11	0.24	0.27
Solid waste < 2 mm.	12	0.36	0.15	5.4	4.66	0.18	0.22	0.16
		0.54	0.12	5.2	3.82	0.23	0.22	0.16
Solid waste < 1 mm.	6	0.40	0.13	6.5	4.66	0.23	0.23	0.13
		0.25	0.11	5.7	4.56	0.25	0.25	0.13

Fraction	Fe	Mn	Cu	Zn	B	Mo	Co	Cr
	ppm dry weight							
Solid waste > 2 mm.[1]	5000	264	95	780	58	2.9	3.4	41
(organic material)	5900	246	121	720	62	2.9	4.1	27
	4700	215	82	650	51			
	4700	241	87	710				
Solid waste < 2 mm.	8500	281	597	670	40	2.1	2.9	18
	10000	291	71	560	50	2.2	2.9	16
					60			
Solid waste < 1 mm.	13500	339	472	670	na[2]	na	na	17
	16500	380	68	700				

[1] Pieces of metal, rubber, glass, etc. > 2 mm (12% of total) were not analyzed.

[2] No analysis.

ratio was considerably greater than the usual ratio of 10 to 12 for humus.

The solid waste contained one to several percent calcium and sulfur, with both elements concentrated in the fine material rather than the organic fraction (Table 6). Moderate amounts of potassium, phosphorus, magnesium, and sodium (0.1 to 0.2%) were found in all the waste fractions. The magnesium content was greatest in the fine material, while the sodium content was higher in the organic fraction.

The fine solid waste material contained over one percent iron. This was not surprising, since the fine fractions included metal fragments and dust as well as organic material. The concentration of manganese, however, was only slightly higher in the fine material than in the organic fraction, and the zinc content was relatively high (about 700 ppm) in all the solid waste fractions. The copper content was quite variable, ranging from 70 ppm to 500 or 600 ppm in duplicate analyses of the fine fractions.

The molybdenum and cobalt content of the solid waste was low (2 to 4 ppm), but the boron and chromium content was relatively high. Chromium was concentrated in the organic material rather than in the fine fractions which contained metal fragments. Apparently most of the chromium was either contained in the organic materials or adhered to their surfaces, rather than occurring in combination with other metals.

In general (copper being the principal exception) the duplicate analyses of the solid waste fractions were in close agreement despite the heterogenous nature of the materials.

The sewage sludge contained moderate amounts of nitrogen, phosphorus, calcium, and iron, with lesser quantities of other metals (Table 7). The levels of trace elements measured, except for molybdenum, fell within the general ranges reported by Berrow and Webber (1972) for a number of municipal sewage sludges. The molybdenum content measured (50 ppm on a dry basis) exceeded the common range by a factor of five. Sewage sludges vary greatly in composition from area to area, however, and this level of molybdenum is not necessarily alarming.

When the quantities of each element applied to the soil in the solid waste and sewage sludge were estimated, the contribution of the sewage was insignificant compared to that of the solid waste (Table 8).

Over 3000 pounds of calcium and 3500 pounds of sulfur were added to the soil per 100 tons of solid waste (Table 8). An excess of these elements should cause no plant problems, however.

Approximately 800 pounds of nitrogen were added per 100 tons solid waste, but this nitrogen would provide little or no fertilizer value. It would be immobilized by micro-organisms as quickly as it

Table 7. Elemental analysis of sewage sludge.

Item	N	P	S	Ca	Mg	K	Na
	%						
Liquid sewage sludge	0.072	0.030	0.016	0.034	0.010	0.010	0.004
with 2.1% solids	0.072	0.030	0.016	0.038	0.009	0.015	0.004
				0.033	0.008		0.004
Average, dry basis	3.4	1.4	0.76	1.7	0.43	0.60	0.19

Item	Fe	Mn	Cu	Zn	B	Mo	Co	Cr
	ppm							
Liquid sewage sludge	496	24	12	52	0.22	1.0	0.24	4.2
with 2.1% solids	510	24	12	60	0.22	1.1	0.25	5.0
	540	24	12	61	0.23			
Average, dry basis	25000	1140	570	2700	11	50	12	220

Table 8. Elements applied in municipal wastes.

Element	Treatment				
	100 tons solid waste[1]	5500 gal sewage	Mineral fertilizer	400 tons solid waste[1]	22000 gal sewage
	lb applied per acre				
N	800	33	up to 2000	3200	132
P	200	14	220	800	55
S	3500	7.4	up to 2300	14000	30
Ca	3300	17	na[2]	13000	66
Mg	170	4.1	na	700	17
K	320	5.8	na	1300	23
Na	300	1.8	up to 0.7	1200	7.4
Fe	800	24	na	3200	94
Mn	33	1.1	na	130	4.4
Cu	20	0.55	na	80	2.2
Zn	93	2.8	10	370	11
B	7.3	0.01	na	30	0.04
Mo	0.36	0.05	na	1.5	0.20
Co	0.47	0.012	na	1.9	0.046
Cr	4	0.21	na	16	0.84

[1] Calculated on the basis of 75% organic material and 25% heterogenous material.

[2] Not applied.

was mineralized, due to the high C:N ratio of the decomposable waste materials.

Large quantities of iron were added in the solid wastes, but would not necessarily be released immediately. The extent of iron oxidation would depend on field conditions; in particular, on the temperature and moisture status of the soil.

Sufficient quantities of phosphorus, potassium and magnesium were added to constitute a potential fertilizer value if they were not immobilized by soil chemical reactions or by micro-organisms.

Almost 100 pounds of zinc were added per 100 tons solid waste, compared to the 10 lb/acre recommended as fertilizer. Except for molybdenum and cobalt, the quantities of micronutrients added in the solid waste exceeded ordinary fertilizer rates, especially with the higher waste applications.

Sources of Boron

After a boron toxicity problem became apparent early in both the greenhouse and the field studies, a separate analysis was conducted to determine the source of the excess boron. Common components of the solid waste were collected as discarded; that is, without mixing and with a minimum of mutual contamination. Each material was analysed for total boron and for water-soluble boron content. The results were compared with similar analyses of the solid waste as a whole, the sewage, and the untreated soil.

The solid waste as a whole contained between 40 and 60 ppm B, with virtually all of the boron in water-soluble form (Table 9). The boron content of the sewage was negligible in comparison. The only material tested which had a higher concentration of boron than the combined waste was the "paper with glue", or more specifically, the glue used in paper products. Paper alone contained only one-tenth as much boron as the glued paper, and this boron may well have come from contamination by the adjacent glued portions. Variability between samples was high because the proportion of glue to paper was not at all uniform, and the samples were not ground before analysis. Even so, most of the boron appeared to be in water-soluble form.

The boron content of the "metal with glue" approached that of the combined solid waste, while the metal alone contained very little boron. More boron was removed from the "metal with glue" by extraction with water than by the ashing procedure, but the difference was small and probably due to sample variability. The glue alone must have contained a high percentage of boron, and most glues are water-soluble.

The food scraps contained about 10 ppm B, but less than half was water-soluble. Cloth contained about 4 ppm B, with most of the boron non-soluble. Both cloth and food scraps are usually minor

Table 9. Boron content of soil, sewage, solid waste, and waste materials collected as discarded.

Item	Description	Total B[1] ppm dry weight, sample a	Total B[1] ppm dry weight, sample b	Water-soluble B[2] ppm dry weight
Sagehill sand	Surface soil (0-6 inches)	0.6	1.1	0.58
Sewage	Anaerobically digested sludge	0.22	0.22	0.23
Solid waste > 2 mm	Organic material only	58	62	51
Solid waste < 2 mm	Hetergenous materials	40	50	60
Glass	Green, brown, clear bottles without labels	0.7	1.5	0.30
Plastic	Bags, containers, rubber glove	0.6	0.8	0.30
Metal	Cans without labels	0.8	1.4	<.02
Metal with glue	Glued portions of cans and labels	26	28	36
Cloth	Cotton and synthetics; various colors	3.4	4.4	0.86
Food scraps	Eggshells, vegetables, banana peel	11	12	4.3
Newspaper	Corvallis, Portland, San Francisco	1.8	2.4	1.7
Paper	Unglued portions of paper bags	8.1	10.1	7.4
Paper with glue	Corrugated cardboard and glued portions of paper bags	85	173	70

[1] Samples were cut into small pieces, dried, ashed at 500° C for 4 hours in a muffle furnace, then digested in HCl. (This procedure does not totally digest the sand, metal, or glass, but should remove any readily accessible boron.) The solutions were tested for boron using a curcumin method.

[2] Samples were cut into small pieces, dried, placed in bottles with distilled water, and shaken overnight. The solutions were filtered and assayed for boron.

components of solid waste, however, while paper products comprise nearly half of the waste. Newspaper, plastic, and glass contained very little boron.

Only the glue can account for the high boron content of the solid waste and the fact that the boron in the waste is water-soluble. A similar phenomenon has been observed in soil testing procedures, where the collection and storage of moist soil samples in unwaxed paper bags can result in boron contamination from the glue in the bags.

RESULTS AND DISCUSSION: GREENHOUSE

Wheat Growth

The addition of municipal wastes had an immediate effect on soil compaction and moisture absorption and retention. When first watered, the soil which received the heavy waste treatments (300 and 400 tons per acre) absorbed very little water. These treatments contained very little soil by volume, and water could move rapidly through the large pore spaces between the coarse solid waste particles. Once wet, however, the waste material retained water excellently. In contrast, the sandy soil retained relatively little water. After the first few days, the wheat plants growing in the soil with the high waste treatments were watered only every four or five days, while the wheat grown with 0, 100, or 200 tons solid waste per acre was watered every other day.

The greatest compaction occurred in the soil treated with 200 tons solid waste per acre. The soil:waste mixture in these pots (approximately 1:1 by volume) settled about 20% within the first few days after planting and watering. The mixtures with 300 tons solid waste per acre settled almost as much, while those with 0, 100, or 400 tons solid waste per acre settled only slightly.

A number of fungi, including two-inch brown mushrooms, a small red fungus on the soil surface, and a white mold along exposed paper edges, appeared on the soil and solid waste mixtures. There were no fungi on the untreated soil, the soil which received sewage only, or the soil with metal pieces and no other solid waste. After about two weeks, small gnats became numerous on the waste-treated soils, especially those with the heavier treatments.

The Hyslop wheat seeds germinated well with all waste treatments except for the 200 ton/acre rate (Table 10). The poor germination with this treatment appeared to be due to waterlogging associated with the greater compaction observed.

On the eighth day after emergence, the tips of the wheat plants turned yellow and brown on all plants grown in the soil treated with solid waste. The tip burn also appeared on several of the plants growing in the untreated soil and in the soil with only sewage waste. In the latter two cases, however, the symptom was more nearly a yellow spot than the pronounced "burning" characteristics observed on the plants grown with solid waste.

Wheat growth was reduced with the addition of solid waste (Table 10). The plants in the soil containing metal pieces from the waste grew well, however, indicating no immediate metal toxicities. Plant growth in the soil which received only sewage materials was comparable to that in the untreated soil, indicating no adverse effects from the sewage.

Table 10. Effect of municipal wastes on wheat germination and growth.

Treatment			Observations		
Solid waste ton/acre	Sewage gal/acre	Nitrogen added lb/acre	Germination[1] %	Height[2] cm	Dry yield[2] gm/40 plants
0	0	80	95	25	2.1
0	0	130	92	29	2.6
0	0	180	98	28	2.2
100	5500	130	88	23	1.1
100	5500	180	98	23	1.5
100	5500	280	90	24	1.8
200	11000	130	52	19	0.8
200	11000	180	42	21	1.2
200	11000	280	50	23	1.2
300	16500	130	82	16	0.9
300	16500	180	92	18	0.8
300	16500	280	88	20	0.9
400	22000	130	90	16	0.7
400	22000	180	90	17	0.7
400	22000	280	98	19	0.9
100	0	130	90	18	0.9
100	0	180	85	23	1.3
100	0	280	80	24	1.4
0	5500	0	98	26	2.3
0	5500	180	98	28	2.4
0	22000	0	98	26	2.4
180[3]	15000	130	92	27	2.6

[1] Ten days after planting.

[2] Three weeks after planting.

[3] Metal sorted from the solid waste.

Plants grown with the higher nitrogen applications were taller and more vigorous at each waste application level. In the untreated soil the wheat responded to the first increment of nitrogen, but there was no response to nitrogen when sewage alone had been added.

The tip burn and reduced plant growth on the waste-treated soils indicated a plant problem associated with the solid waste material, but not with the sewage or the metal in the solid waste. The cause of the problem was not immediately clear: it could have been due to a potassium deficiency, high salt accumulation, or a micronutrient toxicity. A chemical assay of the wheat tissue was conducted to assess the problem.

Elemental analysis of the wheat plant tissue indicated no major deficiencies (Table 11). The potassium and calcium contents were high, but excess of these elements should not cause the observed leaf tip burn. Phosphorus, sulfur, and magnesium contents fell within normal plant levels, and sodium content was relatively low. A high salt accumulation in the leaf tissue was not eliminated as a potential problem, but the combined sodium, potassium, calcium, and magnesium concentrations did not seem excessive.

The manganese and copper levels were within a normal range (Table 11). The iron content was increased somewhat in the wheat grown on sewage-treated soil without solid waste, and zinc content

Table 11. Tissue analysis of wheat grown with municipal waste treatments.

Solid waste ton/acre	Sewage gal/acre	Nitrogen added lb/acre	P	S	Ca	Mg	K	Na	Fe	Mn	Cu	Zn	B
			%						ppm				
0	0	80	0.35	0.58	0.76	0.19	7.06	0.027	107	34	18	50	
0	0	130	0.35	0.62	0.70	0.17	6.75	0.080	100	36	13	34	13[1]
0	0	180	0.35	0.76	0.74	0.18	6.58	0.052	106	37	15	35	
100	5500	130	0.31	0.65	0.61	0.13	5.11	0.050	74	44	16	53	
100	5500	180	0.31	0.74	0.59	0.16	4.74	0.045	105	50	12	60	108[1]
100	5500	280	0.29	0.73	0.51	0.16	5.18	0.045	90	40	12	80	
200	11000	130	0.38	0.50	0.67	0.14	5.02	0.122	89	84	23	49	
200	11000	180	0.38	0.61	0.61	0.14	5.37	0.076	89	71	18	45	
200	11000	280	0.27	0.76	0.52	0.15	5.28	0.134	80	68	18	48	
300	16500	130	0.34	0.62	0.67	0.14	4.41	0.131	91	27	16	74	
300	16500	180	0.37	0.76	0.76	0.15	4.68	0.095	84	43	13	58	
300	16500	280	0.31	0.73	0.64	0.14	4.81	0.066	86	55	11	66	
400	22000	130	0.42	0.61	0.73	0.13	4.83	0.068	106	45	19	84	
400	22000	180	0.41	0.67	0.64	0.14	4.89	0.087	85	48	15	78	349[1]
400	22000	280	0.39	0.78	0.59	0.14	4.72	0.081	78	64	16	100	
100	0	130	0.35	0.75	0.79	0.16	5.39	0.030	87	53	15	41	
100	0	180	0.26	0.67	0.63	0.14	5.20	0.020	85	59	13	47	
100	0	280	0.19	0.71	0.50	0.15	4.69	0.039	84	72	18	48	
0	5500	0	0.39	0.68	0.77	0.20	6.46	0.007	130	31	14	34	
0	5500	180	0.42	0.69	0.77	0.18	6.00	0.015	150	35	11	42	
0	22000	0	0.49	0.66	0.84	0.18	5.20	0.035	115	30	9	52	
180[2]	15000	130	0.49	0.73	0.72	0.18	6.30	0.055	120	46	20	70	

[1] Composite sample including plants from all nitrogen treatments.

[2] Metal sorted from the solid waste.

increased with the solid waste treatments. Neither of these elements reached toxic levels in the plants.

Plant uptake of boron increased markedly with the waste treatments. The normal boron content of wheat is 3 to 5 ppm (Sauchelli, 1969). Wheat grown on the untreated soil contained 13 ppm B, somewhat high; wheat grown with 100 tons solid waste per acre contained about 100 ppm B. The wheat grown with the highest waste treatment contained about 350 ppm B, an increase of 100 times the normal. Boron at these levels is detrimental to wheat growth and could account for the tip burn and poor growth observed.

The soil-waste mixtures used in this initial study were remixed in June 1972, after six months in the greenhouse. The paper and cardboard materials seemed fairly well decomposed, while the metal, glass, and plastic had not changed noticeably. The pots containing the higher waste treatments (200, 300, and 400 tons solid waste per acre) were only about half full, due to compaction and decomposition.

Boron Toxicity from Municipal Wastes

In the second greenhouse experiment, boron toxicity symptoms appeared on all the crops grown with municipal waste applications. Growth rates were affected by the waste additions and by nitrogen fertilizer rates. Heavy nitrogen applications also lowered the soil pH appreciably (Tables 12, 13, and 14).

Initial bean germination was excellent in the soil treated with 0, 50, and 400 tons solid waste per acre, but decreased markedly with the addition of 100 or 200 tons solid waste per acre (Table 12). The reduced germination probably resulted from compaction of the waste materials, which was most pronounced in the pots which contained 200 tons solid waste per acre. The pots with 400 tons solid waste per acre contained very little soil, and the waste materials did not compact as densely as the soil-waste mixtures.

The dry weight of bean plant tissue decreased with increased waste application (Table 12). Nitrogen was limiting in the untreated soil: beans fertilized at 150 lb N/acre were strongly chlorotic, and those fertilized at 300 lb N/acre were slightly yellow. In the waste-treated soil, beans fertilized at 300 lb N/acre were a normal green color. Slightly higher plant yields were obtained with treatments of 1000 lb N/acre, but the plants appeared a darker green color than normal, an indication of another nutrient deficiency or toxicity.

Boron toxicity symptoms appeared on all plants grown in waste-treated soil. With 50 to 100 tons solid waste per acre, the youngest bean leaves were cupped down with chlorosis along the veins and leaf edges. When 200 tons of solid waste were applied, the boron toxicity symptoms were marked. All the leaves were small and cupped or wrinkled with many chlorotic spots and curled

Table 12. Effect of municipal wastes on bean germination, growth, and uptake of boron.[1]

Treatment			Observations			
Solid waste ton/acre	Sewage gal/acre	Nitrogen added lb/acre	Germination %	Dry yield gm/plant	Boron content ppm	Soil-waste pH[2]
			First crop[3]			
0	0	150	97	1.9	17	na[4]
0	0	300	94	2.7	16	na
50	2750	300	97	1.3	29	na
100	5500	300	69	1.0	36	na
200	11000	300	53	0.53	516	na
400	22000	300	97	0.23	878	na
50	2750	1000	97	1.7	31	na
100	5500	1000	75	1.5	40	na
200	11000	1000	59	0.49	414	na
400	22000	1000	100	0.15	776	na
			Second crop[5]			
0	0	250	91	1.8	na	7.0
0	0	500	88	2.2	na	6.7
50	2750	500	100	1.5	na	6.9
100	5500	500	100	1.2	na	6.8
200	11000	500	88	1.2	na	6.5
400	22000	500	97	0.26	na	6.4
50	2750	1800	85	1.1	na	6.2
100	5500	1800	69	1.1	na	5.8
200	11000	1800	96	0.38	na	5.6
400	22000	1800	72	0.20	na	5.5

[1] Average of four replicates.

[2] pH of soil-waste mixtures measured after the second bean harvest.

[3] Planted June 10 and harvested July 10.

[4] No analysis

[5] Planted July 12 in the re-mixed soil and waste; harvested August 11.

Table 13. Effect of municipal wastes on wheat, alfalfa, and fescue germination and growth.[1]

Treatment			Observations	
Solid waste ton/acre	Sewage gal/acre	Nitrogen added lb/acre	Germination %	Dry yield gm/plant
		Wheat[2]		
0	0	200	98	0.52
0	0	400	98	0.83
50	2750	400	98	0.60
100	5500	400	95	0.65
200	11000	400	83	0.49
400	22000	400	87	0.51
50	2750	1400	96	1.37
100	5500	1400	90	1.30
200	11000	1400	88	0.73
400	22000	1400	83	0.42
		Alfalfa[3]		
0	0	50	48	0.49
0	0	200	46	0.69
50	2750	200	47	0.08
100	5500	200	49	0.23
200	11000	200	48	0.30
400	22000	200	33	0.04
50	2750	600	43	0.50
100	5500	600	39	0.24
200	11000	600	34	0.39
400	22000	600	32	0.13
		Fescue[4]		
0	0	250	85	0.58
0	0	500	86	0.82
50	2750	500	81	0.49
100	5500	500	72	0.68
200	11000	500	64	0.37
400	22000	500	68	0.16
50	2750	1800	69	0.71
100	5500	1800	53	0.87
200	11000	1800	55	0.47
400	22000	1800	62	0.16

[1] Average of four replicates.

[2] Planted June 10 and harvested July 24.

[3] Planted June 10 and harvested July 31.

[4] Planted June 10 and harvested August 11.

Table 14. pH of soil-waste mixtures after crop harvests.[1]

Treatment Solid waste ton/acre	Sewage gal/acre	Nitrogen lb/acre	Observations Soil-waste pH		
			Alfalfa		
0	0	50	7.3		
0	0	200	7.0		
50	2750	200	7.5		
100	5500	200	7.5		
200	11000	200	7.4		
400	22000	200	6.8		
50	2750	600	6.1		
100	5500	600	6.6		
200	11000	600	6.4		
400	22000	600	5.6		
			Beans	Wheat	Fescue
0	0	250	7.1	7.4	7.6
0	0	500	6.5	6.9	7.2
50	2750	500	6.9	7.0	7.2
100	5500	500	6.9	7.1	7.1
200	11000	500	6.4	7.3	7.0
400	22000	500	6.2	6.2	6.6
50	2750	2000	4.6	5.2	4.6
100	5500	2000	4.5	4.8	4.7
200	11000	2000	4.3	5.2	5.3
400	22000	2000	4.1	4.3	4.3

[1] Average of four replicates.

edges. Many of the young bean leaves were shriveled drastically before full development. Extreme boron toxicity symptoms occurred on the beans grown on the soil treated with 400 tons solid waste per acre. The plants were dwarfed and leaves very few, very small, wrinkled, and covered with brown spots and chlorotic patches.

The bean plants grown on Sagehill sand, with no waste added, contained normal boron levels of approximately 17 ppm (Table 12). The boron content of the plants grown on soils which received 50 or 100 tons solid waste per acre was about 30 ppm. At 200 and 400 tons solid waste per acre the boron content was 400-500 ppm and 800 ppm, respectively. This extremely high boron content in the bean tissue severely inhibited growth.

The second bean crop germinated well except for the higher nitrogen treatment in combination with the 100 and 400 ton solid waste treatments. Yields were generally lower in the second harvest although the plants had developed more fully into the flowering stage before harvest than had the first crop. Boron toxicity symptoms were slightly less severe, but the plants grown with the highest rate of nitrogen fertilizer (1800 lb N/acre) appeared very dark green and stunted. Yields were depressed compared with yields from the corresponding waste treatments which received only 500 lb/acre.

The pH of the soil-waste mixtures was measured after the second bean harvest (Table 12). The pH decreased slightly with increased waste application, but an additional decrease of nearly one pH unit was associated with the highest rate of nitrogen. Nitrogen was applied as ammonium sulfate, and the oxidation of the ammonium ions to nitrate would release protons, thus increasing soil acidity. The pH depression to below 6.0 would be expected to induce nutrient deficiencies and/or toxicities in beans; the dark green color observed may have been due to a phosphorus deficiency or manganese toxicity.

Wheat germination in the waste-treated soil was generally high (Table 13). Wheat plants fertilized at rates of 200 and 400 lb N/acre were very yellow, while those which received 1400 lb N/acre were green. Plant yields were increased by the added nitrogen except at the highest rate of waste application. Yields were reduced progressively with higher waste additions. The wheat grew very poorly with 400 tons solid waste per acre; the plants were green but frail and readily subject to lodging.

A tip burn was observed on all wheat plants grown on waste-treated soil. This symptom became progressively worse with increased waste applications, affecting about one-quarter inch of each leaf on plants grown with 50 tons solid waste per acre and about two inches on plants grown with 400 tons solid waste per acre. On some leaves a white edging extended down from the "burned" tip;

this edging is characteristic of boron toxicity.

Alfalfa seed germination was very poor with all treatments (Table 13). Nodulation was also poor and a nitrogen response was observed. Yields were erratic with respect to waste treatment, but reduced below those from the untreated soil. Chlorotic leaf edges gave evidence of boron toxicity; these appeared more frequently on plants grown with the higher waste treatments.

Fescue seed germination was good in the untreated soil but declined with increasing waste and nitrogen treatments. Fescue growth was stimulated by the nitrogen fertilizer, however, especially with the lower waste treatments. Yields were greatly reduced with the higher rates of waste application (200 and 400 tons solid waste per acre). A tip burn appeared with all waste treatments but was no more pronounced at the higher rates.

Several "volunteer" tomato and squash seedlings appeared on the solid waste mixtures. One tomato seedling was transferred to another pot with 200 tons solid waste per acre; it was maintained, grew to a four-foot height, and produced small ripe fruit. The plant was affected by a leaf edge burn, but showed no other deficiency or toxicity symptoms.

The soil-waste mixtures were re-mixed in November 1972, after five months in the greenhouse, and pH measurements were made (Table 14). In general, the soil pH decreased by one-half unit with increasing waste treatments. Little further change in pH occurred with a nitrogen fertilizer rate of 200 lb N/acre. At rates of 500 or 600 lb N/acre, the pH decreased by about one unit; at 2000 lb N/acre, by a little over two units. When the highest waste treatment was combined with the highest nitrogen fertilizer rate, the pH dropped to between 4.0 and 4.5, an extremely acid condition detrimental to most crops. This acidity, however, resulted primarily from nitrification of the very large quantity of ammonium ions added rather than from decomposition of the organic wastes.

RESULTS AND DISCUSSION: FIELD PLOTS

Plant Growth

Germination and early growth of the fall-seeded Hyslop winter wheat were adversely affected by seedbed conditions. On the check plots and with the two lower waste application rates (100 and 200 tons solid waste per acre), the seedbed was loose and fluffy except where it had been compacted by tractor wheels. Germination was only moderately good, but sufficient to provide cover to prevent wind erosion. With the highest waste application rate (400 tons solid waste per acre), very little soil was mixed with the coarse waste materials and seed contact was poor. The seed drill could not penetrate the waste uniformly; some seed was left exposed on the surface, while some was completely covered with large pieces of paper or plastic. Germination and seedling survival rates were very low on these plots, resulting in a cover stand of only five to ten percent.

Due to the late planting date, the wheat grew only two to four inches during the fall of 1971. Some slight frost damage occurred during the winter, causing a tip burn and some yellowing around the edges of wheat leaves. These symptoms appeared to be more common on the plants on waste-treated plots, and may have indicated a nutrient imbalance as well, but growth was insufficient for clear diagnosis.

The wheat grew quite vigorously during late March and early April, reaching a height of about 12 inches before it was rototilled. Wheat growth was greatest on the check plots, with no noticeable difference in growth at fertilizer rates of 80, 130, or 180 lb N/acre. On the plots which received 100 tons solid waste per acre, growth was slightly less vigorous than on the check plots, and plants grown with 130 or 180 lb N/acre were a lighter green color than those which received 280 lb N/acre. Wheat stands on the plots with 200 tons solid waste per acre were 25% less than on the check plots; plants grown with 130 or 180 lb N/acre were chlorotic and reduced in height. Wheat plants on the plots with 400 tons solid waste per acre were few and scattered, but green at all nitrogen levels. Growth was less vigorous than on the other waste-treated plots.

No yield measurements were made since the wheat served primarily as a winter cover.

Good stands of fescue and alfalfa were established in April 1972 on the plots which received 0, 100, and 200 tons solid waste per acre. Stands were spotty on the plots which received 400 tons solid waste per acre. The alfalfa on the waste-treated plots started very slowly and exhibited nitrogen deficiency symptoms which disappeared as the growing season progressed. A tip burn appeared on fescue plants on the waste-treated plots, evidence of a nutrient imbalance.

Extensive rabbit damage was observed on many plots prior to the first harvest in June. Rabbits tended to congregate in the green, irrigated plot area. The damage was random throughout the plot area and reduced yields at the first cutting (Table 15). Many plots also contained numerous weeds, such as cheat grass and Russian thistle, typical of the surrounding brush land. Russian thistle was especially prevalent in areas where irrigation was initially inadequate. Some wheat also grew back after the spring rototilling, and scattered plants of squash, tomatoes, lambsquarters, and turnip appeared on waste-treated plots.

Good yields of alfalfa and fescue were obtained in the second cutting (Table 15). Alfalfa yields on the plots which received 0, 100, and 200 tons solid waste per acre varied between 2.3 and 2.8 tons per acre; an increase in nitrogen application rate appeared to increase yields with these treatments. With the highest waste treatment (400 tons solid waste per acre), alfalfa yields were reduced and no nitrogen response was observed. No consistent difference in fescue yield was observed with increase in waste applied. Increased nitrogen fertilization up to 1000 lb N/acre increased fescue yields on all except the plots with 100 tons solid waste per acre. However, a further increase to 2000 lb N/acre decreased yields. This very high rate of nitrogen fertilization was associated with a drop in soil pH

Table 15. Effect of municipal wastes on alfalfa and fescue yield, 1972.[1]

Treatment		Yield			
Solid waste ton/acre	Nitrogen lb/acre	June 29	Aug. 3	Sept. 10	Total yield ton/acre
		---------- ton/acre ----------			
		Alfalfa			
0	0	0.59	2.26	1.94	4.79
0	200	1.45	2.61	2.07	6.13
0	400	1.90	2.54	2.19	6.63
100	200	0.70	2.55	2.06	5.31
100	400	1.21	2.80	2.28	6.29
100	600	1.21	2.80	2.16	6.17
200	200	0.53	1.97	2.20	4.70
200	400	0.86	2.51	2.07	5.44
200	600	0.71	2.44	2.17	5.32
400	200	0.12	2.15	1.79	4.06
400	400	0.05	1.35	1.47	2.87
400	600	0.09	1.71	1.73	3.53
		Fescue			
0	250	0.65	1.91	1.04	3.60
0	500	1.49	2.68	2.21	6.38
0	1000	1.38	2.97	2.49	6.84
100	500	1.07	2.72	1.68	5.47
100	1000	1.34	2.65	1.95	5.94
100	2000	1.28	2.27	2.15	5.70
200	500	0.74	3.03	2.26	6.03
200	1000	0.84	3.11	2.24	6.19
200	2000	0.69	2.52	2.21	5.42
400	500	0.53	2.76	1.77	5.06
400	1000	0.55	3.29	2.23	6.07
400	2000	0.32	2.19	1.67	4.18

[1] Average of three replicates; individual plot yields reported in Appendix II.

to approximately 5.3 in June, and the pH remained low on these plots throughout the season.

The weed problem had diminished by the time of the second cutting, although Russian thistle was still evident at the south end of the plot area, where irrigation problems persisted. Rabbit damage affected yields much less than at the first cutting. A fence was erected around the plot area to minimize such damage in the future.

At the third cutting, yields of alfalfa and fescue were lower than at the second cutting, due to rabbit damage and to a water shortage. Because of a pump breakdown, no water was applied for a period of one week shortly after the second cutting.

Total alfalfa yield for the 1972 season exceeded six tons per acre on the check plots and on the plots which received 100 tons solid waste per acre, except at the lowest nitrogen rate (Table 15). Yields decreased slightly with solid waste treatments of 200 tons per acre, and were reduced appreciably with 400 tons per acre. The highest total fescue yields were produced on the check plots which received 1000 lb N/acre. Good yields (approximately six tons fescue per acre) were produced on waste-treated plots with this rate of nitrogen fertilization. Nitrogen applied at a rate of 500 lb/acre was insufficient for maximum yields; on the other hand, nitrogen applied at 2000 lb/acre decreased soil pH sufficiently to reduce fescue growth.

During the winter of 1972-73 many of the fescue plants were heavily damaged by frost. The damage was selectively greater on those plots with vigorous, succulent plant growth (in general, on those plots which received the highest nitrogen treatment regardless of waste treatment). Re-growth on these plots was very uneven. Since the uneven stands would have adversely affected yields, introducing an unwanted variable, all the fescue plots were rototilled and re-seeded to Fawn fescue in the spring of 1973. Germination was good but the plants were slow to become established. A tip burn appeared again on the fescue grown on waste-treated plots.

The alfalfa over-wintered in good condition; the plants were green and vigorous in the spring of 1973. Stands were excellent except for a few bare patches on some of the plots with the highest waste treatment.

The plot area was generally free of weeds during the 1973 season, and rabbit damage was slight. Difficulties arose with the irrigation system, however, and the plots were without water for several short periods during the summer. They became quite dry during a two-week shutdown in early August, just before the third harvest.

Alfalfa yields at the first cutting were higher in 1973 than in 1972, since the stands were now well established, but lower than in 1972 at the later cuttings due to the drier conditions. In general, alfalfa yield declined with increased waste application. Total yields decreased progressively from over five tons per acre on the check plots to about four tons per acre on the plots with the highest waste treatment (Table 16).

Fescue growth was insufficient at the time of the first alfalfa cutting (May 31, 1973) for a harvest to be made. The intermittent dry periods when the irrigation system was not in operation retarded growth of the young, shallow-rooted fescue much more severely than the established alfalfa. The fescue plots were harvested at the second cutting (July 11), but yields were small. Plant growth improved with increased waste application; the waste additions may have increased moisture retention in the soil. A positive nitrogen response occurred at all levels of waste application. At the third cutting, yields had improved on all plots. Total yields of about two tons per acre were obtained on the check plots with a nitrogen fertilizer rate of 600 lb/acre and on the waste-treated plots with rates of 300 or 600 lb N/acre (Table 16).

In summary, solid waste application to forage cropland should not exceed 200 tons per acre. Poor seedbed conditions and reduced plant growth resulted when 400 tons per acre were applied. Maximum alfalfa yields were obtained in 1972 from plots which received 0 or 100 tons solid waste and 400 pounds nitrogen per acre. Alfalfa yields were not increased when additional nitrogen was applied.

Table 16. Effect of municipal wastes on alfalfa and fescue yield, 1973.[1]

Treatment		Yield			
Solid waste ton/acre	Nitrogen lb/acre	May 31	July 11	Aug. 22	Total yield ton/acre
		--------- ton/acre ------------			
			Alfalfa		
0	0	1.45	2.35	1.76	5.56
0	0	1.41	2.14	1.45	5.00
0	0	1.29	2.38	1.67	5.34
100	0	1.26	2.22	1.47	4.95
100	0	1.04	2.18	1.90	5.12
100	0	1.24	2.14	1.42	4.80
200	0	1.38	1.89	1.35	4.62
200	0	1.32	1.87	1.43	4.62
200	0	1.34	1.95	1.13	4.42
400	0	1.10	1.84	1.60	4.54
400	0	1.02	1.63	1.27	3.92
400	0	0.99	1.77	1.40	4.16
			Fescue		
0	150	0	0.15	0.80	0.95
0	300	0	0.20	0.86	1.06
0	600	0	0.60	1.29	1.89
100	150	0	0.24	0.74	0.98
100	300	0	0.70	1.23	1.93
100	600	0	0.96	1.64	2.60
200	150	0	0.17	1.11	1.28
200	300	0	0.74	1.60	2.34
200	600	0	0.94	1.37	2.31
400	150	0	0.38	0.49	0.87
400	300	0	0.86	1.35	2.21
400	600	0	1.07	0.82	1.89

[1] Average of three replicates; individual plot yields reported in Appendix II.

Maximum fescue yields were obtained when 1000 lb N/acre were applied; higher nitrogen application depressed yields due to increased acidity. Fescue yields decreased slightly with all waste applications, compared to yields from the check plots.

Water stress decreased alfalfa yields in 1973 and severely injured the fescue planted that year. The highest alfalfa yields were again obtained from the plots which received 0 or 100 tons solid waste per acre. Fescue growth was greatest on the waste-treated plots which received 300 or 600 lb N/acre.

Waste Decomposition

Considerable decomposition of paper products occurred during the winter of 1971-72 despite cold temperatures and low precipitation (less than 15 in/yr in the Boardman area). By spring 1972 the larger pieces of cardboard and the more resistant materials such as plastic and rubber were becoming more obvious. After the spring seedbed preparation the plots which received 100 or 200 tons solid waste per acre appeared very similar, with the waste materials well mixed into the soil. On the plots which received 400 tons solid waste per acre, the waste materials created a rough surface appearance. No odor or insect problems were noticeable.

By the end of the first growing season, almost all paper had decomposed into non-identifiable organic residues. Metal products showed considerable oxidation, with iron stains in the sand around the metal pieces.

When the fescue plots were rototilled in the spring of 1973, there was little difference in appearance between the check plots and those with the two lower waste treatments. Only scattered pieces of plastic and rubber were noticeable on the waste-treated plots. With the highest waste treatment, pieces of plastic, rubber, and cloth were evident but well mixed with the soil. Metal pieces were well-rusted and easily broke into fragments.

In September 1973 a trench dug across a check plot (5F) and a plot with the highest waste treatment (4F) showed that the remaining waste materials were concentrated within the upper 12 inches and were most abundant at the soil surface. The upper six to eight inches of the waste-treated plot contained large amounts of organic "duff" and the soil directly beneath this layer was a darker brown color than at the same depth on the check plot. There was little color difference between the plots at a depth of two feet.

Organic matter content and soil microbial populations in March 1973 were compared on the check plots, the plots with the highest waste treatment, and undisturbed soil adjacent to the plot area (Table 17). Soil organic matter and total nitrogen content were not appreciably affected by irrigation and cropping, but were more than doubled by the waste additions. This may simply reflect

Table 17. Effect of waste and fertilizer treatments on the organic matter content and microbial populations of surface soil.

	Undisturbed	Fertilized	Waste treated and fertilized
Treatment:			
Solid waste, ton/acre	0	0	400
Sewage, gal/acre	0	0	22000
Nitrogen added, lb/acre	0	400-1000[1]	400-1000[1]
Irrigation	no	yes	yes
Soil properties:			
pH	7.6	6.9	6.9
Organic matter, %	1.3	1.4	3.5
Total nitrogen, %	0.04	0.05	0.11
Microbial population:			
Bacteria/gm soil (x 10^6)	2	60	155
Fungi/gm soil (x 10^3)	35	45	1000
Algae/gm soil (x 10^3)	2	52	37

[1] Alfalfa plots received 400 lb N/acre; fescue plots received 1000 lb N/acre.

the large amount of organic material in the wastes, or it may indicate that the waste residues are less easily decomposed than are forage crop residues.

The bacterial population increased 30-fold with irrigation and cropping on the check plots and nearly 80 fold with the further addition of municipal wastes. This represents a large increase in substrate turn-over, necessary to support the large numbers of bacteria. Crop residues probably served as the primary bacterial substrate, since the major increase occurred on the check plots as well as on the waste-treated plots. In contrast, the fungal population increased only slightly with irrigation and cropping on the check plots, but 30-fold on the waste-treated plots. The high-carbon paper products in the solid waste probably served as the primary substrate for fungi. Two fungal species, *Trichoderma lignorum* and *Aspergillus clavatus*, were particularly abundant in soil from the waste-treated plots, together comprising 50% of the count. Algae increased by a factor of 25 on the check plots, probably due to irrigation and the addition of fertilizer; they were slightly less numerous on the waste-treated plots.

In summary, the addition of organic waste materials to the soil greatly stimulated fungal activity. The first flush of decomposition probably lasted several months, but was essentially complete by the end of the first growing season. A residue of resistant organic material remained in the surface soil and microbial populations remained high. Metal wastes began to disintegrate within the first year, but hard plastics and rubber showed no evidence of decomposition.

Soil Physical Properties

The bulk density of the Sagehill soil decreased appreciably with waste application, both in a laboratory study and on the field plots (Table 18). The decrease was due to the low density of the added waste material and to an increase in soil pore space resulting from the incorporation of large, fluffy pieces of material. The decrease was less pronounced in the field than in the laboratory since greater decomposition occurred in the field and the plots had been tilled and compacted more thoroughly.

In a laboratory study, using surface soil at moisture tensions from saturation to 15 bars, the soil moisture retention increased progressively with waste application (Table 18). On the field plots, moisture retention at field capacity increased with waste application in the surface 0 to 6 inches of soil, but no difference in moisture retention was measured at a depth of 12 to 18 inches, just below the incorporated wastes.

The water storage capacity of the soil, calculated from laboratory measurements at moisture tensions of 0.1 and 15 bars, decreased when municipal waste was applied. On the field plots, however, water storage capacity calculated on the basis of field capacity measure-

Table 18. Effect of municipal wastes on soil physical properties.[1]

Soil parameter	Treatment: 0 tons solid waste per acre	200 tons solid waste per acre	400 tons solid waste per acre
Bulk density (gm/cc):			
Laboratory, after one month	1.45	0.72	0.32
Field, after one year	1.48	1.26	0.94
Moisture retention (% volume):			
Laboratory, after one month,			
at saturation	42	62	74
at 0.33 bar tension	11.5	16	26.5
at 15 bars tension	5	10	15
Field, after one year,			
0-6 inches at field capacity	22	28	38
12-18 inches at field capacity	21	18	21.5
Water storage capacity:			
Laboratory (in water/ft soil)	1.65	1.20	na[2]
Field (in water/ft soil)	2.0	2.4	3.8
Evaporation water loss:			
Laboratory, accumulative loss 12 days after irrigation (gm/pot)	500	430	260
Infiltration:			
Field (in/hr)	1.0	1.0	1.7
Wind erosion:			
Soil loss on a five-minute exposure to a 30 mph wind (ton/acre)	26	8	0.3

[1] Data from C. H. Ullery, in: Volk and Ullery, 1972.

[2] No analysis.

ments increased with waste application. Field capacity in the waste-treated soil apparently corresponded to a moisture tension below 0.1 bar, and considerable moisture was retained at low tensions by the porous waste materials.

Evaporation water loss was measured by weight loss from saturated soil under greenhouse conditions. Water loss decreased when 200 or more tons solid waste were applied to the soil (Table 18), due to the increase in soil porosity and in the proportion of large pores, which reduced the unsaturated conductivity of the soil.

The infiltration rate of the soil, measured under simulated sprinkler irrigation of moist field plots, was not affected by the waste additions except at the highest rate of waste application.

Wind erosion, measured using air-dry soil placed in a wind tunnel, was reduced with increasing waste application, since the shredded waste on the surface served as a windbreak. The waste itself was sufficiently mixed into the soil so that it was not dislodged by winds of 30 miles per hour.

In summary, the addition of municipal wastes reduced the bulk density of the soil while it increased the soil moisture retention and water storage capacity, at least during the first year after waste application. These changes occurred only in the surface soil, but could significantly affect initial plant growth. Surface evaporation and infiltration, were influenced only at the highest rate of waste application, but effective wind erosion control was obtained with all waste additions.

Soil physical changes due to the waste materials would be expected to diminish with time as the wastes became more completely decomposed. However, some effects of the waste additions probably remained through the second season, as evidenced by the organic "duff" remaining in the soil in September 1973.

Soil pH and Conductivity

The pH of the surface soil in the plot area averaged 8.1 before the plots were established (Appendix I). By April 1972, six months after municipal wastes and nitrogen fertilizer had been applied, the soil pH decreased appreciably on all plots. Several processes could have been involved: addition of acids in the waste materials, nitrification of the ammonium sulfate fertilizer, and decomposition of the waste materials with the release of acids. The sandy soil probably had little buffering capacity, and relatively small acid additions or transformations could have influenced the pH noticeably.

With the lowest rate of nitrogen fertilization, 80 lb N/acre on the check plots, soil pH decreased to 6.8 in April 1972 (Table 19). With 130, 180, or 280 lb N/acre on the plots which received 0, 100, or 200 tons solid waste per acre, the pH dropped to about 6.0. Apparently nitrification proceeded too slowly during the winter to convert all of the ammonium added at the higher fertilizer rates to

Table 19. Soil pH and conductivity, 0-6 inches, April 1972.[1]

Solid waste ton/acre	Nitrogen applied fall 1971 lb/acre	pH	Conductivity mmho/cm
0	80	6.8	1.02
0	130	6.1	1.36
0	180	6.3	1.74
100	130	5.8	1.40
100	180	5.8	1.95
100	280	6.0	2.22
200	130	6.4	2.47
200	180	6.2	2.45
200	280	6.2	3.32
400	130	6.9	2.35
400	180	7.0	2.87
400	280	7.0	3.08

[1] Average of three replicates.

nitrate, with the release of protons. The ammonium sulfate fertilizer would not increase soil acidity until this process occurred.

The municipal waste materials had a complex effect on soil acidity. Considerable decomposition was evident during the winter and many of the waste materials were probably converted to organic acids. This process could account for the lower pH measured on the plots with 100 tons solid waste per acre, compared to the check plots with the same nitrogen treatments (Table 19). Decomposition must have been proceeding as rapidly on the plots with higher waste applications, but the effect on soil pH was apparently balanced by increased levels of soluble salts.

Soil conductivity, a measure of total soluble salts, increased only slightly with the addition of 100 tons solid waste per acre (compared to the check plots with the same nitrogen treatments) but rose by over 50% with the addition of 200 or 400 tons solid waste per acre. This could account for the slight rise in pH measured with the increase in waste application from 100 to 200 tons per acre.

With the increase in waste application from 200 to 400 tons per acre, soil pH increased to neutral. This large increase in pH cannot be attributed to an increase in soluble salts _per se_ but rather to an abrupt increase in the proportion of sodium ions in solution. The extractable sodium content in April 1972 increased from 0.1 me/100g on the check plots to 0.5 me/100g on the plots with 200 tons solid waste per acre, then to an average of 3.5 me/100g on the plots with 400 tons solid waste per acre.

Soil conductivity was moderately high on all plots in April 1972, and increased with nitrogen fertilization as well as with waste treatments (Table 19). With solid waste applications of 200 or 400 tons per acre, and with 100 tons per acre plus the highest nitrogen treatment, the soil conductivity exceeded 2.0 mmho/cm. Salt-sensitive crops could be adversely affected at this level (Richards, 1954). However, in no case did the conductivity reach 4.0 mmho/cm, a level at which many crops are adversely affected by excess salts (Richards, 1954) and soils can be classified as slightly saline (USDA, Soil Survey Manual, 1962). Since wheat, alfalfa, and fescue are moderately salt tolerant (Richards, 1954), their growth was probably not affected by the increase in total salts on the waste-treated plots.

By June 1972 the soil pH had increased over that measured in April on both the check and the waste-treated plots which received the lower rates of nitrogen fertilization (up to 600 lb N/acre). The increase was most pronounced at the lowest nitrogen rate (Table 20), and could be due to the upward movement of salts during dry periods between irrigations. No consistent change in pH was measured with waste additions at a given nitrogen application rate. Apparently the acids and bases released during the initial flush of waste decomposition had been neutralized or leached into the subsoil, and the remaining waste materials decomposed too slowly to affect soil pH.

Soil pH decreased progressively with increased nitrogen fertilization, indicating that nitrification was proceeding rapidly under the warm, moist summer conditions (Table 20). With an application rate of 1000 lb N/acre to the fescue plots, the pH remained near 6.0, while with 2000 lb N/acre, the pH dropped to between 5.1 and 5.6 and remained low throughout the season. On the alfalfa plots the decrease in pH was much less pronounced,

Table 20. Soil pH and conductivity, 0-6 inches, June 1972 to September 1973.

Solid waste ton/acre	Nitrogen applied 1971-72 lb/acre	pH[1] June 1972	pH Sept. 1972	Conductivity Sept. 1972 mmho/cm	Nitrogen applied 1973 lb/acre	pH[1] March 1973	pH Sept. 1973	Conductivity Sept. 1973 mmho/cm
				Fescue plots				
0	250	8.2	8.2	0.45	150	7.0	8.6	1.00
0	500	7.3	7.3	0.93	300	6.6	6.8	1.45
0	1000	6.3	6.9	0.89	600	6.3	6.4	2.60
100	500	6.9	7.2	0.80	150	5.9	7.9	1.4
100	1000	6.2	6.9	0.58	300	5.8	7.4	1.03
100	2000	5.6	6.0	0.93	600	5.5	4.9	2.80
200	500	6.9	6.8	2.35	150	6.5	7.3	1.55
200	1000	6.1	6.4	1.92	300	5.9	6.3	2.0
200	2000	5.1	5.5	0.82	600	5.2	5.3	2.65
400	500	7.2	7.2	0.70	150	7.0	7.4	1.4
400	1000	6.2	6.3	0.70	300	5.8	6.3	1.85
400	2000	5.4	5.4	0.65	600	5.3	4.9	1.5
				Alfalfa plots				
0	80	8.4	7.5	na[2]	0	7.5	7.6	na
0	200	7.5	7.6	na	0	7.0	8.0	na
0	400	6.9	7.4	na	0	7.0	7.2	na
100	200	7.8	7.6	na	0	7.0	7.7	na
100	400	7.0	7.3	na	0	7.0	7.2	na
100	600	7.0	6.8	na	0	6.8	7.3	na
200	200	7.4	7.0	na	0	7.1	7.6	na
200	400	7.0	7.1	na	0	6.8	7.4	na
200	600	6.8	6.8	na	0	6.7	7.5	na
400	200	7.4	7.4	na	0	7.0	7.8	na
400	400	7.1	7.2	na	0	7.1	7.2	na
400	600	7.2	7.3	na	0	7.2	7.5	na

[1] Average of three replicates.

[2] No analysis.

since nitrogen application rates were lower.

In September 1972 the soil pH followed the same pattern as in June, with higher values for some plots but no consistent trend with time. The conductivity was reduced appreciably on all but two of the plots measured, and the effects of the nitrogen and waste treatments were no longer evident. Irrigation exceeded consumptive use during the 1972 season and net downward water movement leached most of the soluble salts from the surface soil.

Residual nitrogen continued to affect soil pH on the fescue plots in 1973. In general, the pH decreased during the winter and increased during the growing season, except on the fescue plots which received the highest nitrogen treatments (Table 20). By September, soil conductivity had increased appreciably compared to that measured in September 1972. The irrigation regime was not maintained evenly during the summer of 1973, and evaporation probably caused net upward movement of soluble salts during the intermittent dry periods. Accumulation of salts in the surface soil could increase soil pH as well as conductivity.

Soil profile samples collected in 1972 and 1973 showed that the subsoil remained strongly alkaline despite surface applications of waste materials and ammonium sulfate (Figure 2). Even when the pH of the surface soil dropped to 5.3 (Figure 2) the soil pH below a depth of 12 inches remained above 8.0. The soil in the

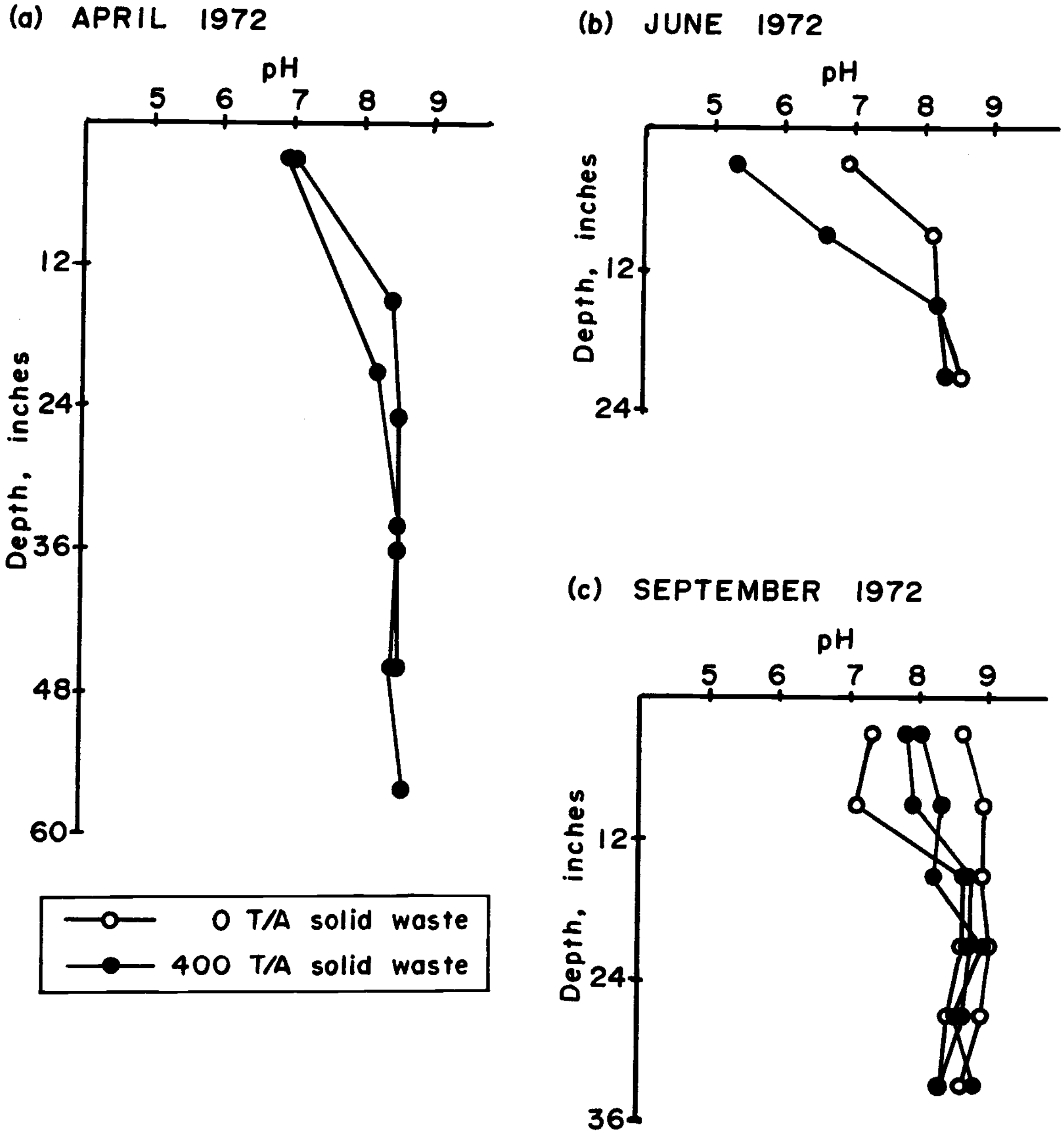


Figure 2. pH in the soil profile.

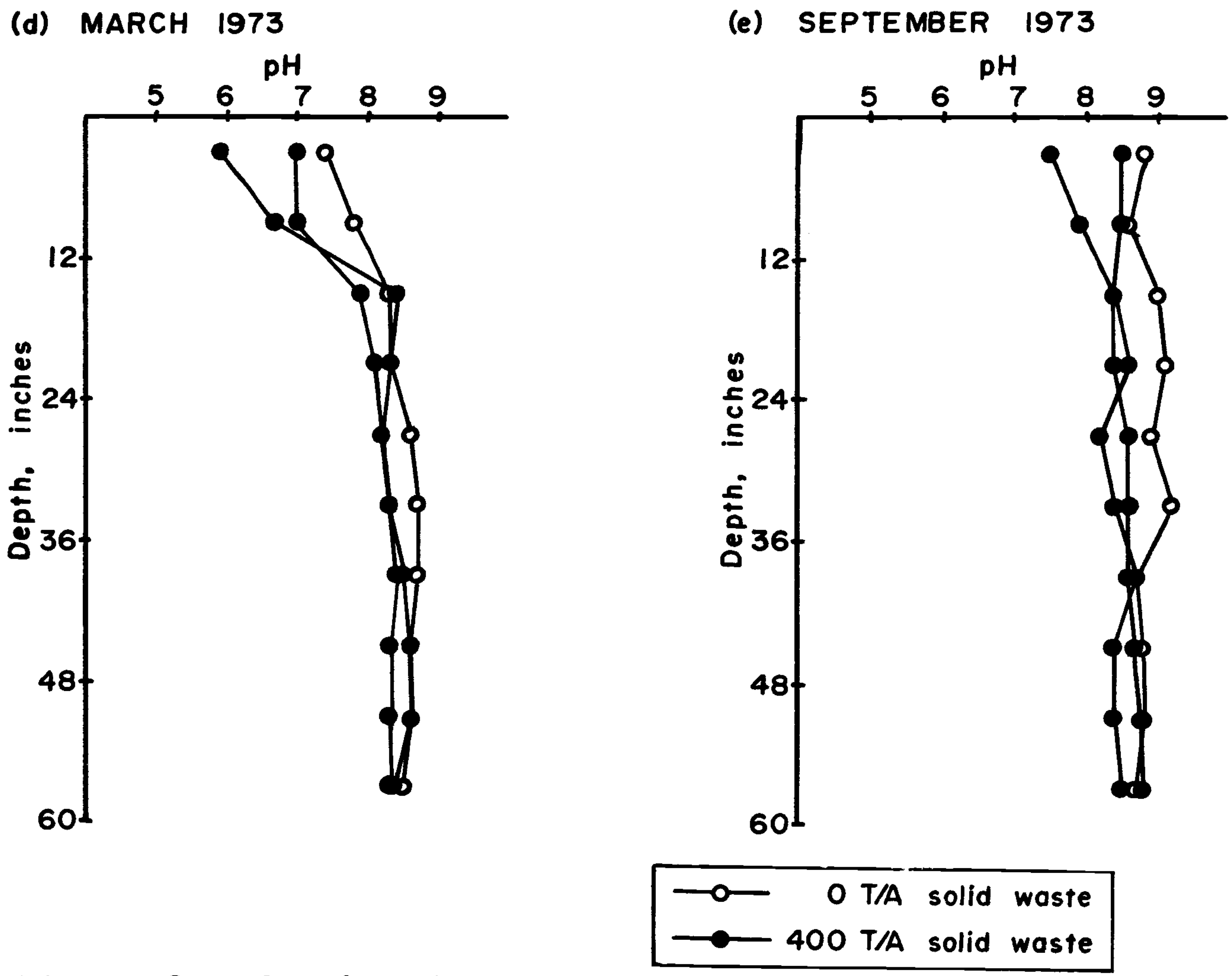


Figure 2. Continued.

plot area contained free calcium carbonate below a depth of about 15 inches and had a weakly cemented caliche layer at about four feet. The excess calcium carbonate would neutralize any acids leached from the surface.

Salts leached through the soil profile with irrigation during the 1972 season and moved back toward the surface with the intermittent dry conditions of 1973. In April 1972 the soil conductivity of plots with the highest waste treatment was about 0.5 mmho/cm below a depth of 12 inches (Figure 3) while the surface conductivity exceeded 2.0 mmho/cm. By September, the conductivity of the surface soil had dropped to 0.7 or less, but one check plot and one waste-treated plot had conductivities greater than 1.0 mmho/cm at a three-foot depth. Most of the soluble salts had apparently been leached below this depth by irrigation. In September 1973 the soil conductivity was variable with depth, generally between 0.5 and 1.0 mmho/cm with occasional peaks near 1.5 mmho/cm. This variability indicates variable water movement in the plots. Salts were moved down or up with irrigation or evaporation and deposited at different depths in the profiles.

Major Plant Nutrients

With the exception of nitrogen, no major plant nutrients (phosphorus, sulfur, calcium, magnesium, and potassium)

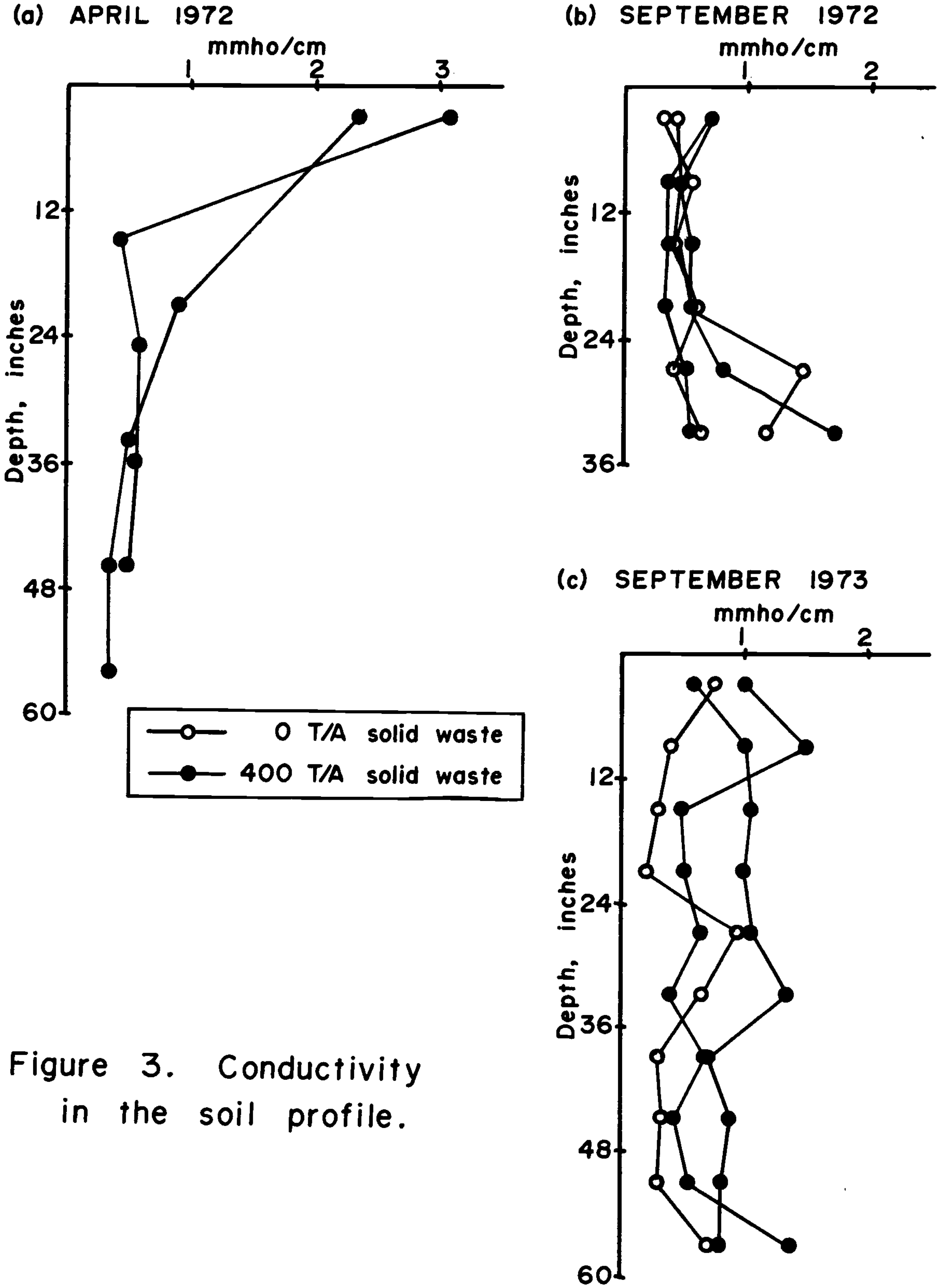


Figure 3. Conductivity in the soil profile.

limited plant growth. The fescue responded to nitrogen fertilization and the nitrogen content of both wheat and fescue increased with the application of ammonium sulfate (Tables 21 and 22). Although the alfalfa seedlings on some plots appeared chlorotic during the first few weeks of growth, and yields were reduced at the lowest rate of nitrogen fertilization, no consistent response to nitrogen was detected in the tissue assay (Table 23). Rhizobium nodules apparently supplied sufficient nitrogen to the plants by the time of the first harvest, so that the reduced yields reflected only delayed nodulation.

The nitrogen content of wheat sampled in April 1972 from the plots which received 400 tons solid waste per acre was higher than that of wheat from the check plots or the plots with lower waste treatments. This may be due to the additional nitrogen applied in the solid waste and sewage materials, or it may be a reverse "dilution effect". That is, plants limited in growth by another factor may accumulate excess quantities of available nutrients that would normally be "diluted" by continuing plant growth. Wheat plant growth was generally poor in April on the plots with the highest waste treatment.

The phosphorus content of the wheat plants sampled in April 1972 increased with waste treatments (Table 21). The soil in the plot area was low in phosphorus when the plots were established and phosphorus fertilizer was not applied until April 1972. The phosphorus supplied in the waste materials probably increased phosphorus

Table 21. Effect of waste treatments on the elemental content of wheat.

Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K	Fe	Mn	Cu	Zn
		%						ppm			
					Harvested in April 1972[1]						
0	80	2.77	0.23	0.34	0.36	0.14	3.07	1470	80	5	37
0	130	2.89	0.24	0.35	0.33	0.13	3.31	865	71	5	25
0	180	3.22	0.22	0.36	0.34	0.15	3.37	1440	86	9	27
100	130	2.24	0.28	0.32	0.36	0.11	2.96	800	67	9	45
100	180	2.78	0.25	0.36	0.34	0.11	3.03	850	67	4	65
100	280	3.45	0.29	0.37	0.37	0.13	3.55	1160	68	6	69
200	130	2.56	0.31	0.30	0.38	0.13	2.83	1430	92	11	68
200	180	2.88	0.32	0.32	0.40	0.14	3.07	1940	93	8	72
200	280	3.19	0.31	0.37	0.37	0.12	3.10	1300	94	13	86
400	130	3.67	0.53	0.39	0.42	0.15	3.56	800	79	6	222
400	180	3.57	0.41	0.37	0.35	0.14	3.08	1125	129	8	249
400	280	3.93	0.46	0.45	0.38	0.16	3.42	1320	123	14	270
					Harvested in June 1972[2]						
0	80	2.53	0.40	0.25	0.28	0.12	2.88	249	72	na[3]	38
0	200	2.64	0.36	0.23	0.19	0.11	2.62	144	72	na	29
0	400	2.72	0.45	0.23	0.20	0.11	3.30	148	71	na	32
100	200	2.23	0.51	0.22	0.18	0.10	2.85	156	54	na	68
100	400	2.40	0.49	0.24	0.20	0.10	3.30	263	63	na	66
100	600	2.20	0.48	0.24	0.23	0.10	2.80	139	61	na	53
200	200	2.44	0.54	0.33	0.24	0.10	3.15	274	40	na	91
200	400	2.37	0.51	0.24	0.20	0.10	3.15	268	77	na	73
200	600	2.77	0.41	0.32	0.24	0.10	2.95	275	68	na	107

[1] Average of three replicates.

[2] One replicate only.

[3] No analysis.

Table 22. Effect of waste treatments on the elemental content of fescue.

Solid Waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K	Fe	Mn	Cu	Zn
		%						ppm			
					Harvested in June 1972[1]						
0	200	2.03	0.36	0.20	0.26	0.16	3.30	114	58	11	29
0	400	3.29	0.45	0.27	0.27	0.19	3.78	157	140	9	39
0	600	3.53	0.45	0.34	0.29	0.20	4.02	144	144	13	44
100	400	3.22	0.44	0.38	0.35	0.21	4.18	182	118	17	93
100	600	3.78	0.45	0.39	0.33	0.23	4.07	172	152	14	92
100	1200	4.25	0.48	0.47	0.36	0.19	4.03	189	194	14	128
200	400	3.11	0.42	0.42	0.37	0.19	3.77	163	107	16	115
200	600	3.42	0.43	0.42	0.33	0.19	3.75	166	135	15	102
200	1200	4.27	0.42	0.50	0.34	0.18	3.78	175	227	14	123
400	400	3.19	0.41	0.41	0.30	0.19	3.83	172	119	15	99
400	600	3.77	0.41	0.59	0.28	0.20	3.45	198	221	19	211
400	1200	4.29	0.43	0.75	0.27	0.19	3.81	180	252	25	268
					Harvested in September 1972[2]						
0	250	1.48	0.13	0.25	0.31	0.21	2.65	180	63	13	25
0	500	2.42	0.15	0.27	0.28	0.26	3.03	323	121	10	43
0	1000	2.52	0.17	0.26	0.29	0.26	3.18	277	161	12	37
100	500	2.83	0.20	0.37	0.28	0.26	3.05	210	119	12	46
100	1000	2.29	0.19	0.34	0.27	0.25	2.88	353	166	12	38
100	2000	3.63	0.24	0.40	0.29	0.20	3.02	237	275	16	76
200	500	2.38	0.18	0.29	0.30	0.21	2.75	313	87	9	45
200	1000	2.61	0.19	0.34	0.30	0.23	3.00	270	122	10	59
200	2000	3.62	0.23	0.36	0.29	0.21	3.16	260	295	14	99
400	500	2.22	0.18	0.32	0.28	0.20	2.84	233	103	10	101
400	1000	3.91	0.21	0.40	0.28	0.22	3.06	317	212	11	145
400	2000	3.43	0.25	0.54	0.30	0.20	3.48	197	334	18	156

Continued

Table 22. Continued.

Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K	Fe	Mn	Cu	Zn
		---------------- %					----------------	---------- ppm			-------
					Harvested in July 1973[2]						
0	100	2.33	0.28	0.29	0.40	0.22	3.18	470	78	8	38
0	200	2.10	0.26	0.29	0.28	0.22	3.45	277	174	8	40
0	400	3.04	0.27	0.28	0.26	0.21	3.38	223	182	9	34
100	100	2.72	0.30	0.29	0.40	0.24	3.69	280	92	8	69
100	200	3.14	0.31	0.28	0.36	0.24	3.95	217	205	10	74
100	400	3.28	0.33	0.30	0.30	0.21	3.56	228	350	12	77
200	100	2.71	0.30	0.27	0.43	0.21	3.33	240	87	10	85
200	200	3.16	0.29	0.29	0.34	0.20	3.80	170	157	11	86
200	400	3.27	0.31	0.37	0.34	0.22	3.74	233	330	10	90
400	100	2.24	0.33	0.25	0.31	0.20	3.44	173	79	9	75
400	200	2.90	0.32	0.33	0.29	0.23	3.78	200	337	18	235
400	400	3.00	0.35	0.33	0.24	0.18	3.72	277	327	12	262

[1] Average of three replicates.

[2] Average of three replicates except for nitrogen analysis of one replicate only.

Table 23. Effect of waste treatments on the elemental content of alfalfa.

Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K	Fe	Mn	Cu	Zn
		%						ppm			
		Harvested in June 1972[1]									
0	80	3.67	0.33	0.37	1.50	0.23	2.71	246	75	19	51
0	200	3.63	0.36	0.32	1.66	0.26	3.05	202	71	11	44
0	400	3.31	0.37	0.28	1.45	0.23	3.00	211	114	15	47
100	200	3.19	0.33	0.37	1.51	0.21	3.11	302	71	17	68
100	400	2.94	0.32	0.43	1.46	0.21	2.73	217	116	24	79
100	600	3.33	0.36	0.44	1.53	0.22	3.01	235	126	13	64
200	200	3.22	0.36	0.42	1.67	0.21	3.06	337	80	16	70
200	400	3.24	0.34	0.46	1.54	0.19	2.66	198	118	14	101
200	600	3.24	0.32	0.47	1.52	0.21	2.87	220	207	10	124
400	200	3.59	0.37	0.57	1.87	0.27	3.05	303	119	13	241
400	400	3.39	0.33	0.51	1.67	0.24	2.57	453	143	21	220
400	600	3.51	0.37	0.70	2.05	0.28	3.03	323	184	19	320
		Harvested in September 1972[2]									
0	80	2.74	0.26	0.26	0.67	0.19	2.36	240	38	10	21
0	200	2.99	0.25	0.25	0.68	0.18	2.14	240	28	10	20
0	400	3.19	0.30	0.29	0.64	0.19	2.47	290	47	11	20
100	200	2.46	0.31	0.27	0.68	0.16	2.54	220	42	9	31
100	400	3.00	0.30	0.29	0.65	0.16	2.57	297	59	9	33
100	600	2.72	0.26	0.31	0.72	0.19	2.39	213	60	10	35
200	200	3.02	0.34	0.30	0.65	0.16	2.41	420	44	10	35
200	400	3.17	0.30	0.29	0.63	0.16	2.55	667	51	10	38
200	600	3.15	0.27	0.33	0.69	0.17	2.40	460	66	10	45
400	200	3.49	0.31	0.29	0.61	0.16	2.53	343	103	9	131
400	400	3.23	0.29	0.30	0.66	0.18	2.34	255	55	10	62
400	600	3.58	0.31	0.36	0.70	0.19	2.54	337	151	14	133

Continued

Table 23. Continued.

Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K	Fe	Mn	Cu	Zn
		%						ppm			
					Harvested in May 1973[2]						
0	0	3.20	0.21	0.25	1.37	0.17	2.65	273	25	13	28
0	0	3.01	0.20	0.26	1.27	0.14	2.22	293	28	12	28
0	0	2.73	0.22	0.32	1.27	0.16	2.50	213	33	14	23
100	0	2.67	0.22	0.38	1.32	0.14	2.50	327	30	15	37
100	0	3.00	0.20	0.26	1.18	0.15	2.65	220	32	14	45
100	0	3.00	0.22	0.29	1.33	0.14	2.57	220	43	11	36
200	0	2.94	0.21	0.44	1.43	0.16	2.36	247	28	13	40
200	0	2.48	0.19	0.35	1.13	0.12	2.45	153	23	13	42
200	0	2.34	0.17	0.30	1.08	0.11	2.38	213	28	11	43
400	0	2.40	0.16	0.34	1.35	0.14	2.33	227	33	9	76
400	0	2.85	0.17	0.35	1.59	0.16	2.36	187	42	11	67
400	0	3.03	0.19	0.36	1.37	0.14	2.48	150	46	11	87
					Harvested in August 1973[2]						
0	0	2.42	0.28	0.29	1.50	0.22	2.46	147	28	15	26
0	0	2.21	0.30	0.41	1.37	0.25	2.41	133	38	9	28
0	0	3.19	0.29	0.46	1.52	0.24	2.62	140	33	11	21
100	0	2.44	0.31	0.29	1.37	0.20	2.69	160	30	14	32
100	0	2.89	0.33	0.33	1.30	0.18	2.61	240	35	10	32
100	0	3.19	0.33	0.42	1.37	0.22	2.55	160	39	14	35
200	0	2.68	0.31	0.45	1.33	0.22	2.61	153	31	na[3]	35
200	0	2.65	0.30	0.41	1.33	0.21	2.47	213	33	16	49
200	0	2.71	0.34	0.50	1.25	0.25	2.59	147	41	14	45
400	0	2.73	0.29	0.39	1.35	0.23	2.61	167	36	11	69
400	0	2.68	0.28	0.51	1.33	0.21	2.60	147	49	14	67
400	0	2.42	0.25	0.34	1.40	0.21	2.74	160	41	19	54

[1] Average of three replicates.

[2] Average of three replicates except for nitrogen analysis of one replicate only.

[3] No analysis.

uptake somewhat with all waste treatments. The phosphorus content of wheat from the plots with the highest waste treatment could have been enhanced because of poor plant growth.

The phosphorus content of the fescue and alfalfa was relatively high in June, then decreased in later harvests (Tables 22 and 23). The triple superphosphate applied in April would have been available for early plant growth but would have become fixed as tri-calcium phosphate as the season progressed, rendering it only slightly available to plants. Phosphorus uptake remained adequate for plant growth, however, and was not affected by waste or nitrogen treatments.

The sulfur content of wheat, fescue, and the first harvest of alfalfa increased somewhat with waste application and nitrogen fertilization. The solid waste applied was high in sulfur (about 35 lb S/ton waste) and nitrogen was applied as ammonium sulfate. The highest plant levels of sulfur were found in the June 1972 samples: up to 0.75% in the fescue and 0.70% in the alfalfa. Reduced growth of grasses and alfalfa has been reported at tissue contents of 0.5 to 0.7% and 0.30 to 0.75%, respectively (Eaton, 1966), although normal alfalfa growth was also reported at 0.29% sulfur. The alfalfa and fescue from the plots which received 400 tons solid waste per acre (except the fescue with the lowest rate of nitrogen) contained more than 0.5% sulfur in June, which could have contributed to the poor growth and reduced yields.

In general, the sulfur levels were lower in September than in June of 1972. Sulfate-sulfur released by decomposition of the waste materials and sulfate-sulfur applied as fertilizer would be leached into the subsoil, while organic sulfur in the waste residues would be available to plants only as it was mineralized. The difference in sulfur content of the fescue and alfalfa due to waste treatments tapered off by 1973 but a slight fertilizer effect remained on the fescue, where additional ammonium sulfate was applied.

The calcium, magnesium, and potassium levels in the plants were not affected by waste or nitrogen treatments. Large amounts of calcium were added in the solid waste (about 33 lb Ca/ton of solid waste), but since the soil already contained abundant free calcium carbonate, the added calcium had no effect on plant uptake. Calcium levels were generally low in the wheat and fescue (Tables 21 and 22) but high in the alfalfa (Table 23). Dicotyledonous plants typically utilize more divalent cations than do monocots, and 1.2 to 1.6% is a normal range for alfalfa (Chapman, 1966). The calcium content of the alfalfa decreased to about 0.7% in September 1972, then increased to 1.3 to 1.4% with the water stress periods and upward movement of salts during 1973. The calcium content of the fescue remained low in both 1972 and 1973, but was adequate for plant growth.

The magnesium content of both fescue and alfalfa was within a normal plant range (Embleton, 1966) and did not vary greatly from harvest to harvest.

The potassium content of the wheat and fescue was generally high, especially in the first cuttings (April 1972, June 1972, and July 1973). Monocotyledonous plants typically utilize more monovalent cations than do dicots, and potassium levels in the alfalfa were somewhat lower than in the wheat and fescue. In all cases the potassium uptake was more than adequate for plant growth (Ulrich and Ohki, 1966), so that the tip burn symptoms observed in the field could not be attributed to a potassium deficiency.

Iron, Manganese, Copper, and Zinc: Plant Uptake

The wheat plants harvested in April 1972 contained high and variable iron levels (800 to 2000 ppm; Table 21), but no relation to waste or nitrogen treatments was detected. Sauchelli (1969) suggests that contamination from soil particles may contribute to analyses of pasture grasses in excess of 500 ppm Fe. Such contamination appears possible in this case, since the young plants were cut close to the ground and the samples were not washed before analysis. Contamination of later samples was less likely because the plants were taller and were not cut as closely to the ground.

The iron content of the wheat harvested in June 1972 and all fescue and alfalfa generally fell within a range of 100 to 300 ppm. Some alfalfa samples, especially in September 1972, contained up to 900 ppm Fe; these samples raised the averages and may indicate local spots of high iron concentration in the soil. Sauchelli (1969) reports, however, that alfalfa may normally contain up to 1000 ppm Fe. No consistent trends related to waste or nitrogen treatments were observed. Iron uptake in general did not increase with the addition of municipal wastes, although local "pockets" of high iron concentration must have occurred adjacent to rusting metal.

The manganese content of the fescue and alfalfa harvested in June increased with waste application and with nitrogen fertilization (Tables 22 and 23). Manganese uptake by the alfalfa decreased with subsequent harvests; in contrast, manganese uptake by the fescue increased slowly but steadily (Figure 4). This upward trend was closely related to the continued nitrogen applications to the fescue plots and the consequent pH reduction. Manganese availability increases with decreasing pH; manganese oxides and hydroxides become more soluble and tetravalent manganese is more readily reduced to soluble divalent ions. When the manganese content of the fescue is averaged across nitrogen treatments and across waste application rates (Figure 5), a manganese increase with waste addition is not consistent, but an increase with nitrogen applied is clear

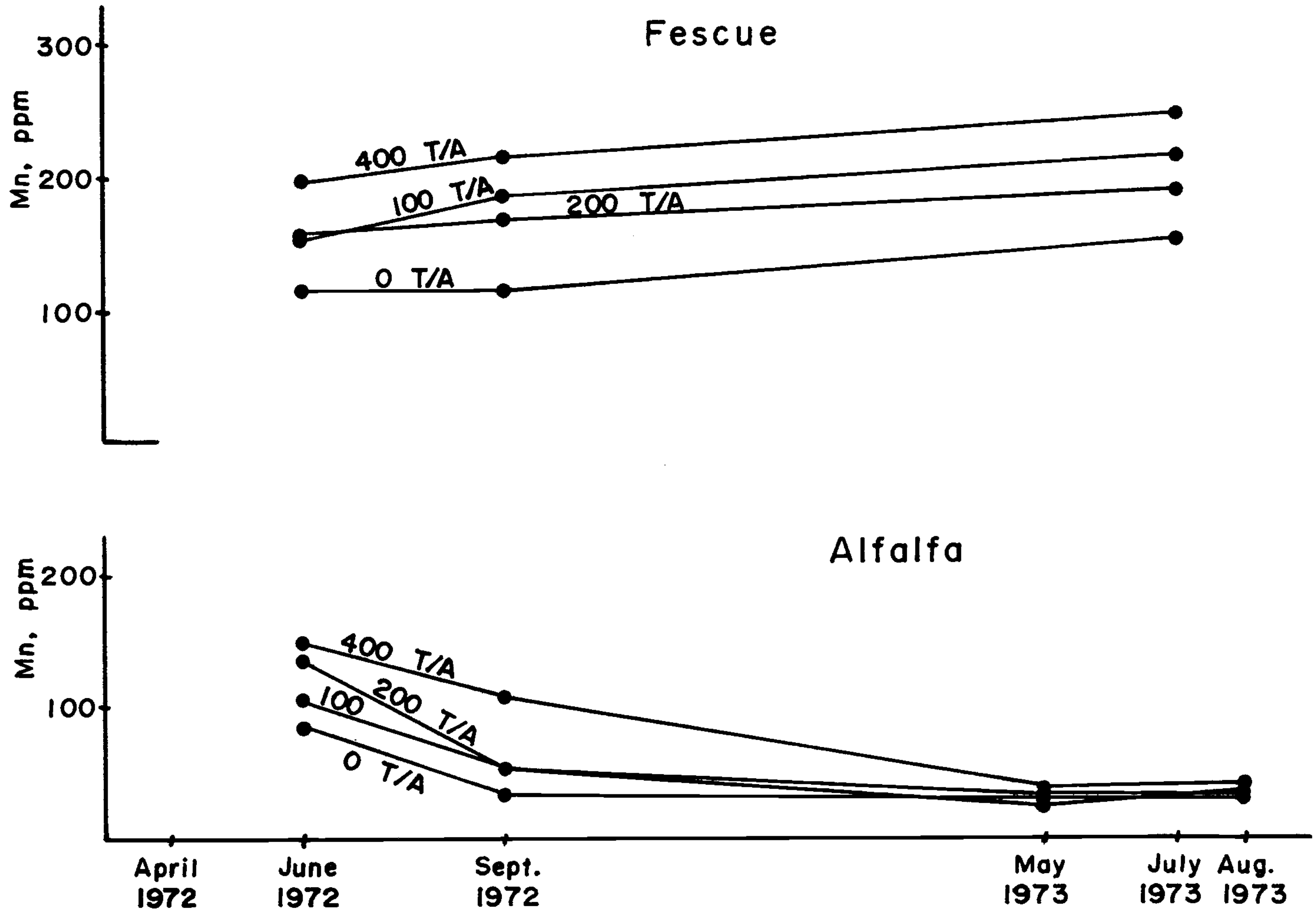


Figure 4. Manganese content of fescue and alfalfa, 1972-73.

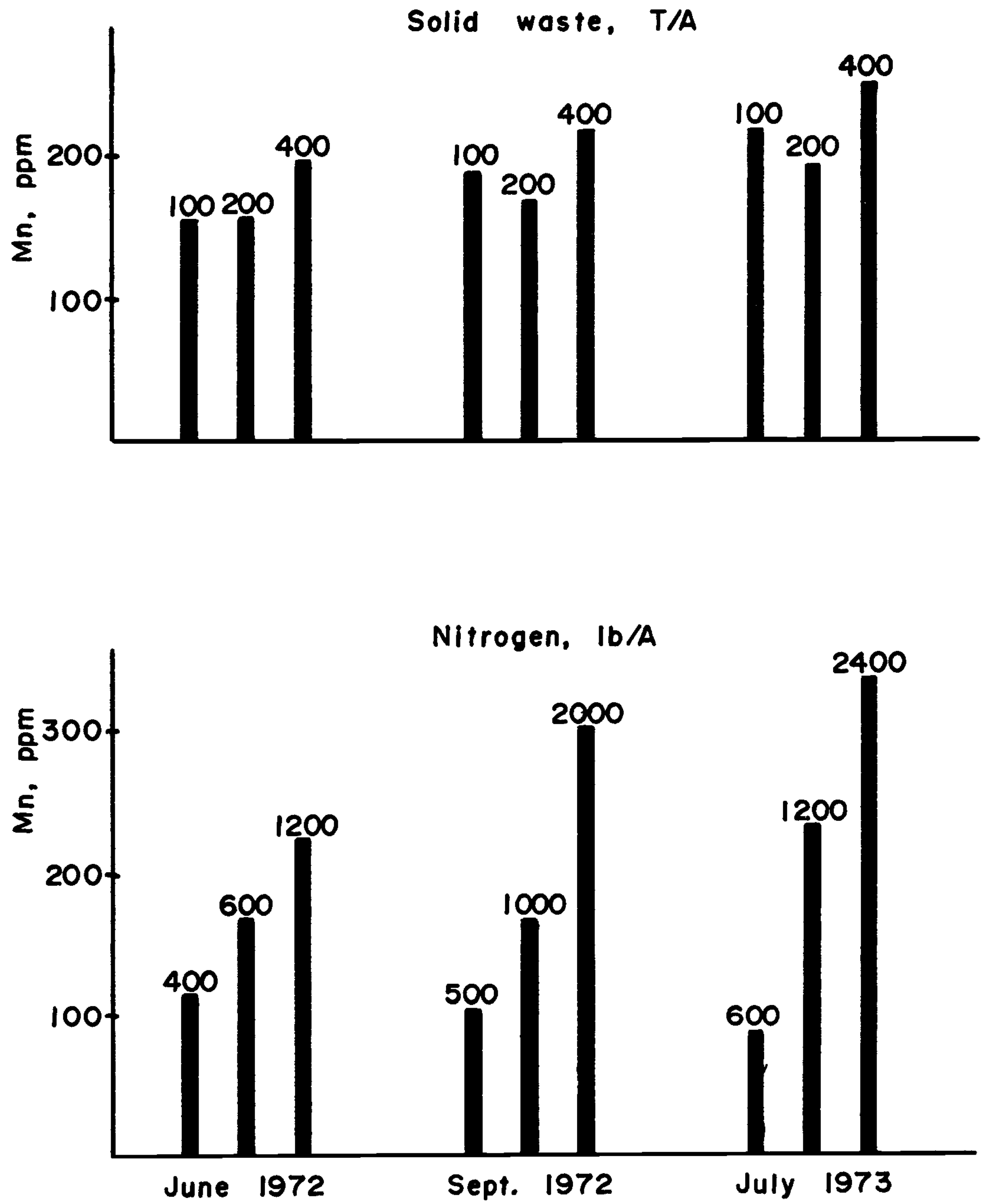


Figure 5. Manganese content of fescue averaged across waste and nitrogen treatments.

and pronounced. A less pronounced increase with nitrogen can be seen in the manganese content of alfalfa harvested in June 1972 (Figure 6), but not in the later harvests when no further nitrogen was applied.

Manganese is generally present in soils in quantities more than sufficient for plant growth, but may be unavailable at neutral or alkaline pH. However, manganese levels were adequate for plant growth and for livestock forage even in plants grown on alkaline soils (those soils which received the lower nitrogen treatments). The manganese content of the alfalfa was never less than 20 ppm, and that of the wheat and fescue remained above 50 ppm. Labanauskas (1966) reports a critical level of 10 ppm Mn for alfalfa and 20 ppm Mn for wheat; Sauchelli (1969) discusses manganese deficiency in cattle whose feed contained about 5 ppm Mn, well below the manganese levels measured in this study.

On the other hand, manganese may have approached toxic levels in the fescue. Fescue from the plots which received the highest cumulative nitrogen treatment, with a pH of about 5.0, contained 300 to 400 ppm Mn. Labanauskas (1966) sets a general lower limit of 400 to 500 ppm for manganese toxicity, but this may over estimate the tolerance of some plants. Gupta (1972) and White (1970) observed manganese toxicity symptoms in barley tissue which contained 200 to 400 ppm Mn.

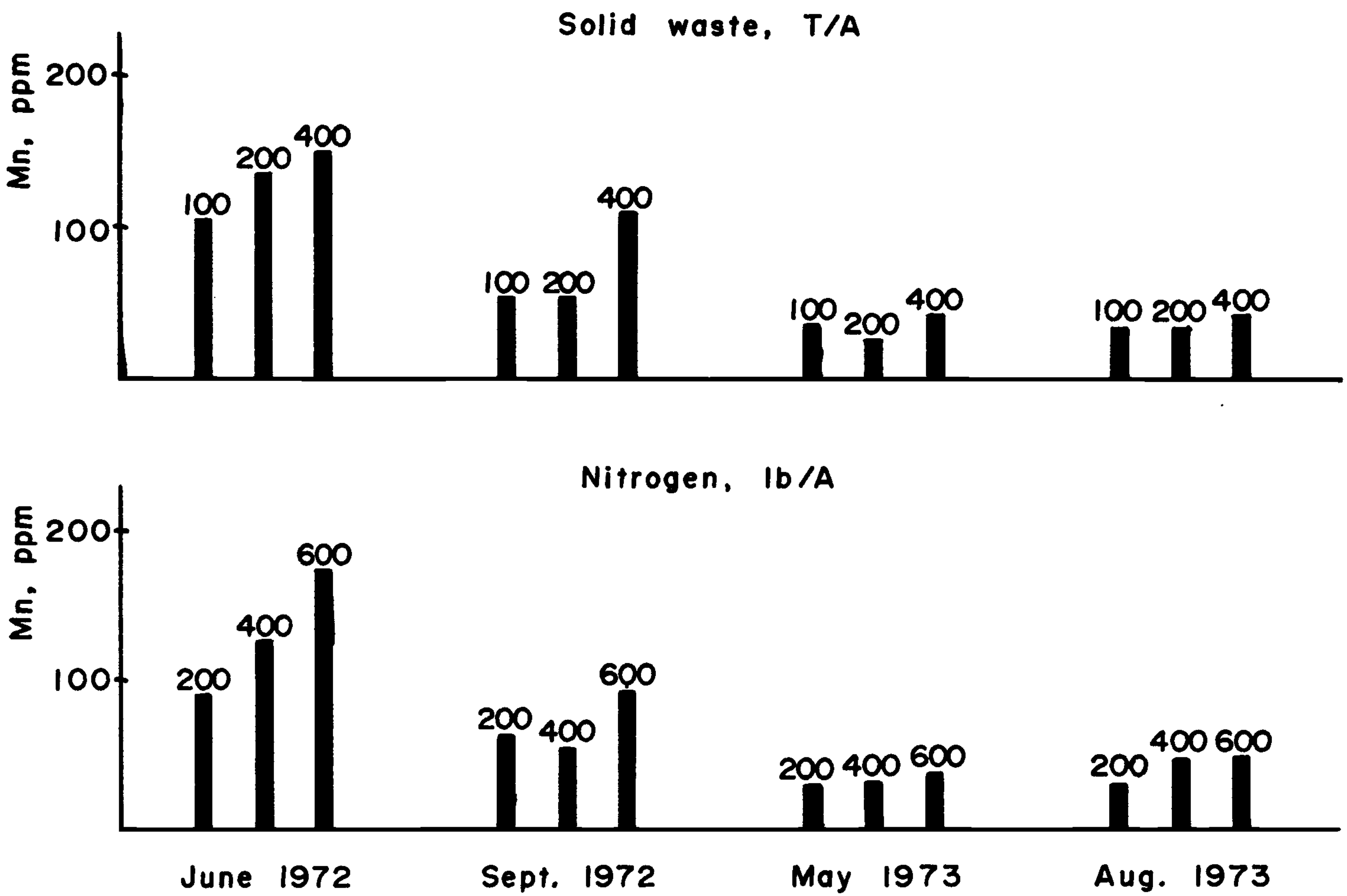


Figure 6. Manganese content of alfalfa averaged across waste and nitrogen treatments.

The copper content of the wheat, fescue, and alfalfa ranged between 5 and 15 ppm with higher values for fescue or alfalfa from some plots harvested in June 1972 (Tables 21, 22, and 23). No pattern with respect to waste or nitrogen treatments was observed. The scattered high values, up to 34 ppm Cu (Appendix IV), may indicate samples collected from local "pockets" of high copper concentration, or may be due to contamination in the plant grinding procedure. Apparently copper added in the waste materials is released very slowly and/or is rapidly immobilized in the soil and remains unavailable to plants.

Normal plant copper levels range between 5 and 20 ppm (Reuther and Labanauskas, 1966) although wheat has been reported deficient at 8 ppm Cu (Sauchelli, 1969). The latter also reports copper deficiency in sheep whose feed contained 5 ppm Cu, but Pringle et al. (1973) report normal metabolism in cattle on a barley-hay ration with 3 to 4 ppm Cu. Copper deficiency in livestock is often related to excess molybdenum and will be discussed in conjunction with molybdenum. Copper may be toxic to plants at tissue levels greater than 20 ppm (Reuther and Labanauskas, 1966).

The zinc content of wheat harvested in April 1972 increased dramatically with the addition of municipal wastes, doubling with application rates of 100 or 200 tons solid waste per acre, and quadrupling again with the application of 400 tons solid waste per acre (Table 21). A blanket fertilizer application of 10 lb Zn/acre to all plots in April did not affect this pattern of uptake, nor did plant maturity. Wheat samples in June 1972 contained about as much zinc as wheat from the same plots in April, and a similar pattern appeared in the fescue and alfalfa harvested in June (Tables 22 and 23). Zinc uptake from plots which received 400 tons solid waste per acre reached levels of 200 to 300 ppm, which may be high enough to interfere with growth. Sauchelli (1969) sets a lower limit of 150 ppm for zinc toxicity in young wheat, barley, and oats; but Chapman (1966) reports only faint chlorosis from induced iron deficiency in oat leaves containing 1700 ppm Zn. Since there were no signs of iron-deficiency chlorosis on the plants grown, it is unlikely that heavy metals such as manganese and zinc were assimilated in sufficient quantity to interfere with plant metabolism.

The zinc content of the fescue and alfalfa increased with waste application (Figure 7) and also with each increment of nitrogen fertilizer (Figures 8 and 9). The fertilizer increased zinc uptake primarily through its effect on soil pH: only 50 ppm Zn, or about one-half pound zinc per 2000 pounds nitrogen, was present as a contaminant in the ammonium sulfate applied. By contrast, 93 pounds zinc were added per 100 tons solid waste.

By September 1972, the zinc content of plants from the plots which received 100 or 200 tons solid waste per acre decreased to

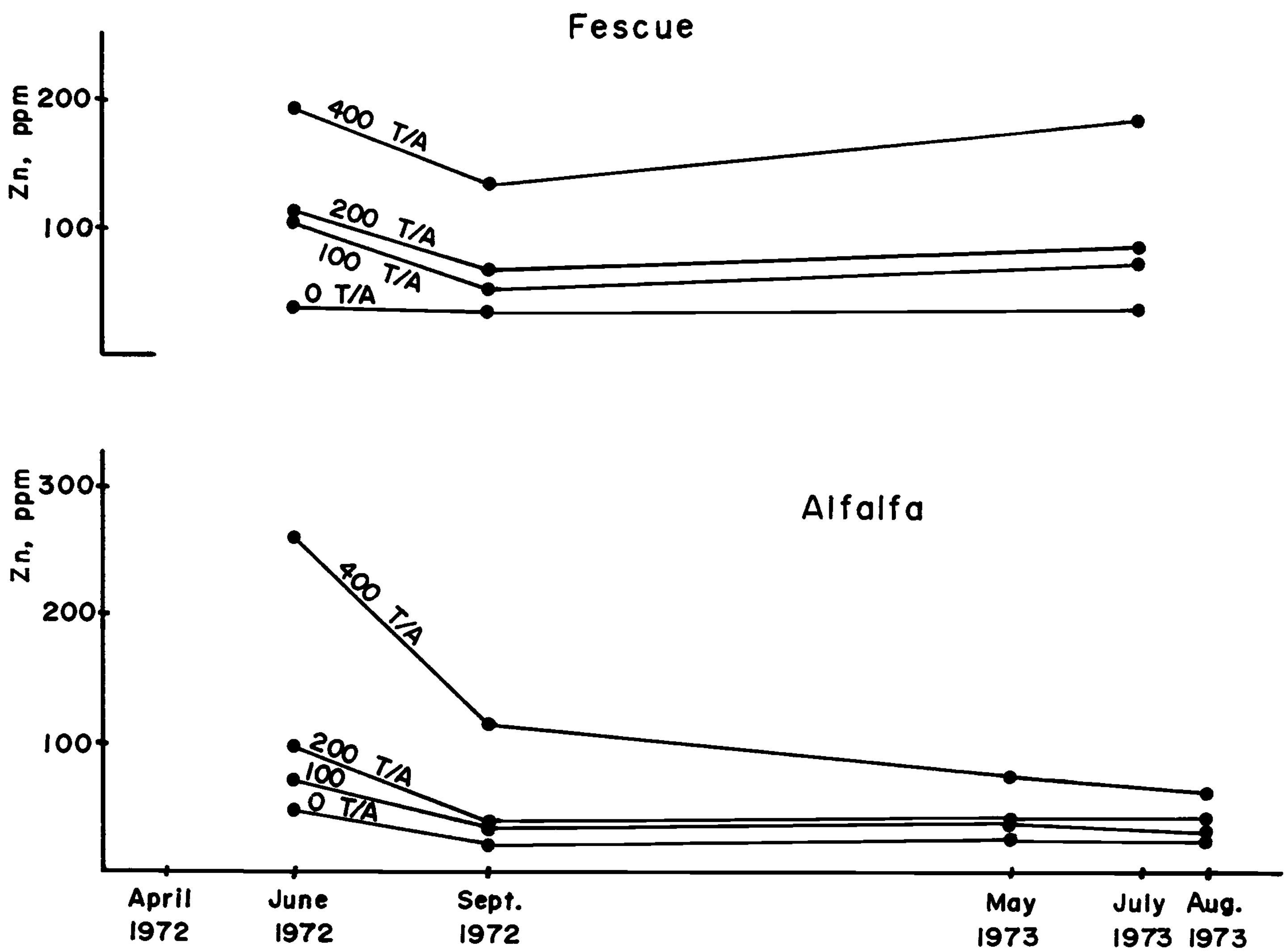


Figure 7. Zinc content of fescue and alfalfa, 1972-73.

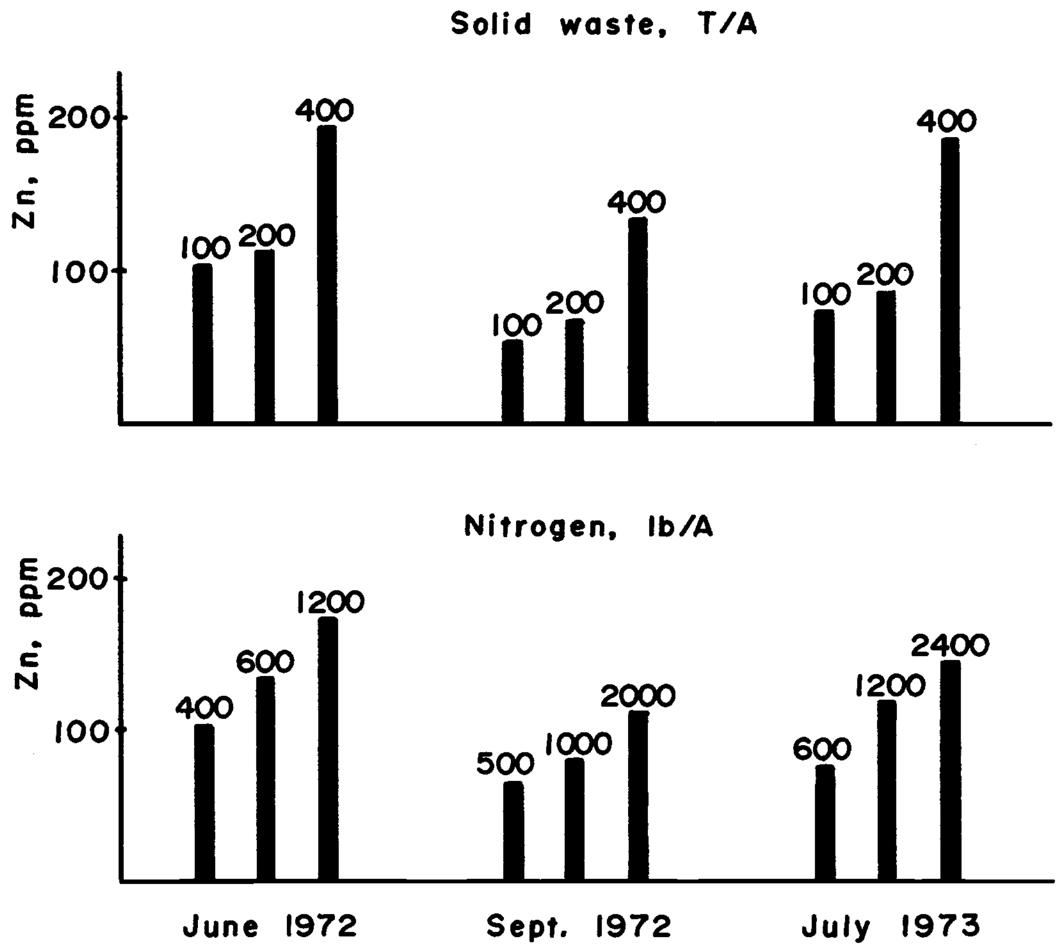


Figure 8. Zinc content of fescue averaged across waste and nitrogen treatments.

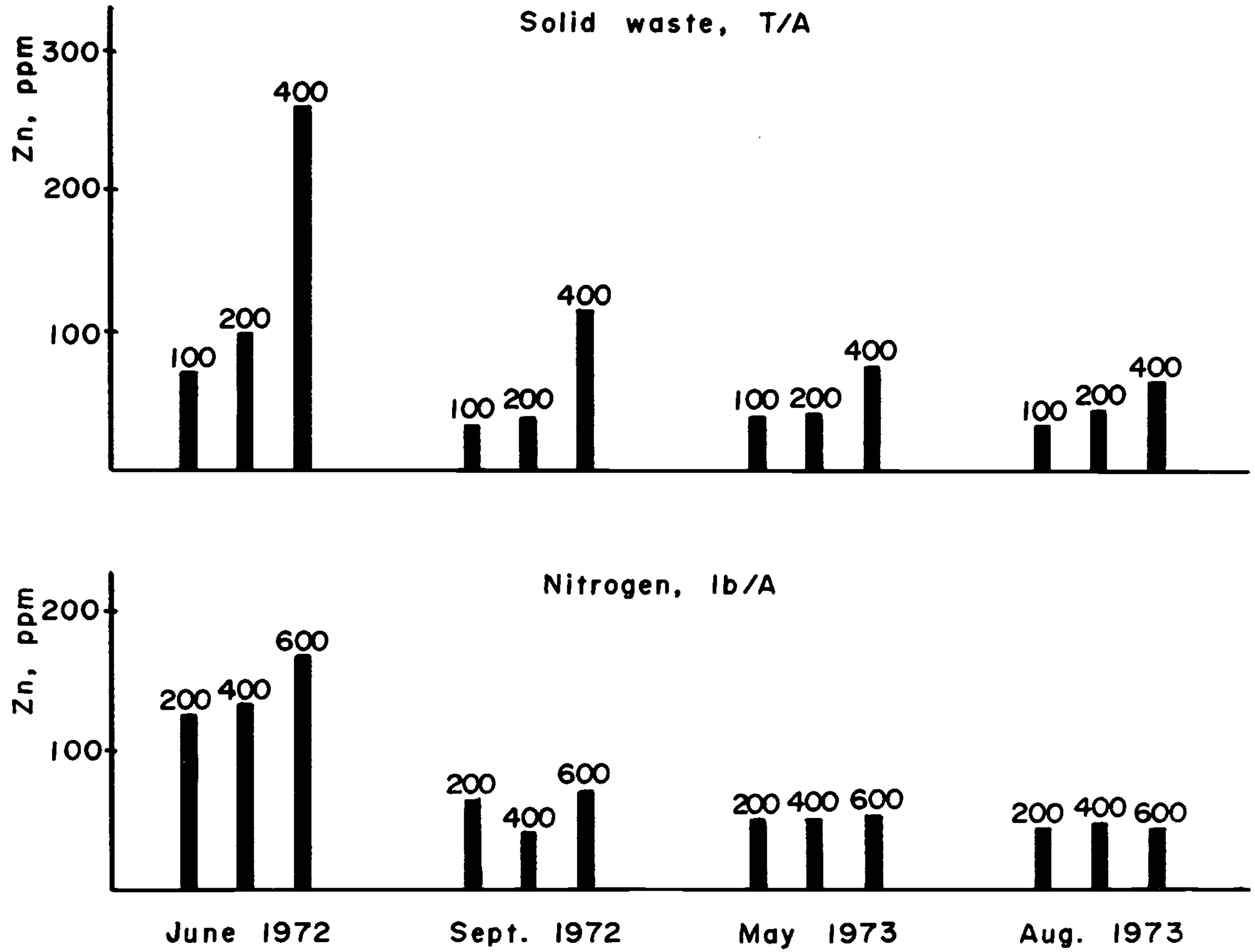


Figure 9. Zinc content of alfalfa averaged across waste and nitrogen treatments.

more normal levels: 30 to 40 ppm in the alfalfa and 40 to 100 ppm in the fescue. But the zinc content of both crops grown on the plots which received 400 tons solid waste per acre remained over 100 ppm. Zinc uptake by the alfalfa from these plots decreased steadily during the next year, but zinc uptake by the rescue remained high (Figure 7).

In 1973, zinc uptake by the fescue followed the same pattern as in 1972, while zinc uptake by the alfalfa decreased in general and was no longer influenced by the nitrogen treatments (Figures 8 and 9).

Zinc levels were low but not deficient in plants grown on the check plots and in the 1973 alfalfa harvests. A minimum of 25 and 20 ppm Zn was measured in the fescue and alfalfa, respectively. Normal growth of wheat has been reported at zinc levels down to 20 ppm; grasses, to 15 ppm; and alfalfa, to 9 ppm (Sauchelli, 1969). Chapman (1966) reports zinc deficiency at 13 ppm in alfalfa but normal growth at 13.8 ppm. Pringle et al. (1973) found that feed containing 25 to 32 ppm Zn was adequate for normal metabolism of cattle.

Iron, Manganese, Copper, and Zinc: Soil Content

The extractable iron, copper, and zinc in the soil in April 1972 increased dramatically with each addition of municipal waste, while extractable manganese increased only with the highest rate of waste application (Table 24). Apparently some of the metals added in the waste were readily released, although there was little evidence of rusting or fragmentation of metal pieces until later in the season.

Plant uptake of iron was not affected by the 50-fold increase in soil iron content on the plots which received the highest waste treatment. Iron is normally abundant in soils, so that added in the waste materials (approximately 8 lb Fe/ton of solid waste) would not necessarily affect the supply of iron available to the plants. In general, no good correlations of plant uptake with soil extraction methods for iron have been reported (Wallihan, 1966). Iron "toxicities" seem to be due to imbalances in the plants associated with deficiencies of other heavy metals such as manganese or copper. Conversely, an excess of other heavy metals may induce an iron deficiency.

The extractable iron content of the soil with the highest waste treatment decreased by September 1972 (Table 24), despite visible rusting of metal in the soil. In 1972 only the surface 0-6 inches of the waste-treated soil were affected by the added iron (Table 25). In 1973, however, a slight increase in extractable iron content was measured to a depth of 18 inches, indicating that some iron had been leached from the surface.

Table 24. Iron, manganese, copper, and zinc content of surface soil (0-6 inches) from fescue plots.

Solid waste ton/acre	Nitrogen lb/acre	Fe	Mn	Cu	Zn
		ppm			
		April 1972[1]			
0	80	3.6	15.8	0.75	0.42
0	130	4.9	24.0	0.74	0.39
0	180	4.5	28.9	0.81	0.39
100	130	11.0	23.2	1.27	16.5
100	180	10.0	29.0	1.37	15.7
100	280	8.6	26.8	1.40	16.6
200	130	29.9	20.3	3.10	49.5
200	180	25.3	18.7	2.68	33.0
200	280	24.3	31.2	2.73	55.3
400	130	190	57.9	19.0	483
400	180	349	71.3	36.4	888
400	280	161	42.8	19.6	684
		September 1972[2]			
0	250	2.5	7.0	0.70	3.03
0	500	14.0	24.5	0.77	0.70
0	1000	7.8	23.9	0.90	1.47
100	500	9.4	18.0	1.77	34.9
100	1000	12.8	33.7	1.61	9.9
100	2000	21.8	24.2	1.37	8.5
200	500	11.3	14.1	3.23	45.2
200	1000	14.8	19.7	2.11	20.4
200	2000	15.5	52.7	2.13	18.4
400	500	11.5	21.3	2.59	31.9
400	1000	45.5	22.3	7.82	97.0
400	2000	18.5	69.5	4.82	82.4

Continued

Table 24. Continued.

Solid waste ton/acre	Nitrogen lb/acre	Fe	Mn	Cu	Zn
		ppm			
		September 1973[2]			
0	150	2.0	6.7	0.70	1.58
0	300	16.8	32.4	0.87	1.75
0	600	22.5	49.3	1.05	4.20
100	150	7.5	15.4	1.19	31.7
100	300	9.4	13.4	1.47	33.7
100	600	34.3	46.5	1.74	8.5
200	150	9.0	17.5	1.82	28.4
200	300	15.9	27.4	1.88	20.2
200	600	16.8	67.6	3.03	21.6
400	150	8.9	13.2	2.35	15.4
400	300	138	50.3	8.32	145
400	600	37.8	73.8	3.57	36.9

[1] Average of three replicates.

[2] One replicate only.

Extractable soil manganese did not increase with the addition of 100 or 200 tons solid waste per acre, but approximately doubled when 400 tons solid waste per acre were added (Table 24). By September 1972, no consistent increase in soil manganese with waste application remained. Manganese increased with the highest nitrogen treatment in the soils which received 200 or 400 tons solid waste per acre, however, indicating that more of the manganese in these soils was in a reduced, available state. By September 1973 a clear increase in extractable manganese with nitrogen fertilization was observed.

Table 25. Iron, manganese, copper, and zinc distribution in the soil profile.

Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	Fe	Mn	Cu	Zn
			ppm			
			April 1972			
400	130	0-6[1]	190	57.9	19.0	483
400	130	15-27	5.3	4.72	1.48	0.74
400	130	27-40	4.0	2.70	0.85	0.28
400	130	40-52	2.2	0.96	0.55	0.45
400	130	52-60	1.8	0.77	0.43	0.32
400	280	0-6[1]	161	42.8	19.6	684
400	280	10-20	5.8	8.50	1.28	0.93
400	280	20-30	4.2	2.76	1.42	0.30
400	280	30-42	3.2	1.19	0.79	0.21
400	280	42-51	2.7	1.23	0.64	0.21
			September 1972			
0	250	0-6	5.4	6.01	0.83	0.50
0	250	6-12	4.3	4.21	0.96	0.10
0	250	12-18	3.6	4.36	1.50	0.04
0	250	18-24	3.9	2.57	1.62	0.02
0	250	24-30	4.7	3.40	1.16	0.04
0	250	30-36	4.0	1.37	0.70	0.02
0	500	0-6	11.8	32.5	1.07	1.38
0	500	6-12	8.8	17.1	1.43	0.46
0	500	12-18	3.6	3.44	1.34	0.54
0	500	18-24	4.9	2.71	1.44	0.20
0	500	24-30	4.7	0.79	0.89	0.13
0	500	30-36	3.8	0.81	0.71	0.26
400	400	0-6	47.5	18.9	10.3	150
400	400	6-12	7.0	20.5	1.89	16.8
400	400	12-18	2.6	7.70	1.37	5.00
400	400	18-24	3.3	3.13	1.41	0.96
400	400	24-30	5.1	2.30	1.34	1.99
400	400	30-36	3.0	1.87	1.08	0.15
400	200-600[2]	0-6	27.0	19.0	2.13	32.7
400	200-600	6-12	5.0	19.0	1.23	1.31
400	200-600	12-18	4.3	12.9	1.37	0.21
400	200-600	18-24	4.3	17.8	1.55	0.27
400	200-600	24-30	3.8	5.29	1.62	0.24
400	200-600	30-36	4.6	2.78	0.89	0.40

Continued

Table 25. Continued.

Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	Fe	Mn	Cu	Zn
			------------ ppm	--------------------		
		September 1973				
0	80-400[2]	0-6	3.0	9.70	0.50	1.63
0	80-400	6-12	2.4	3.05	0.74	0.36
0	80-400	12-18	2.0	2.74	1.23	0.19
0	80-400	18-24	2.4	2.14	1.30	0.13
0	80-400	24-30	2.6	2.13	1.05	0.08
0	80-400	30-36	4.1	1.95	0.86	0.09
0	80-400	36-42	3.5	1.01	0.63	0.09
0	80-400	42-48	2.1	1.04	0.57	0.08
0	80-400	48-54	1.9	1.25	0.52	0.08
0	80-400	54-60	1.7	1.57	0.86	0.23
400	200-650[2]	0-6	21.0	14.0	3.17	32.9
400	200-650	6-12	19.7	15.0	4.30	64.9
400	200-650	12-18	17.0	9.5	2.15	7.03
400	200-650	18-24	4.0	3.97	1.54	1.24
400	200-650	24-30	5.3	2.73	1.11	0.92
400	200-650	30-36	3.9	1.80	0.65	0.57
400	200-650	36-42	3.1	1.72	0.56	0.45
400	200-650	42-48	2.4	1.43	0.44	0.14
400	200-650	48-54	2.1	1.41	0.42	0.34
400	200-650	54-60	1.9	1.23	0.40	0.18
400	600-2600[2]	0-6	71.3	17.0	11.3	480
400	600-2600	6-12	25.0	15.9	4.60	360
400	600-2600	12-18	10.7	28.4	2.61	59.2
400	600-2600	18-24	5.0	16.2	2.50	12.4
400	600-2600	24-30	4.7	8.40	1.34	1.03
400	600-2600	30-36	5.5	4.76	1.35	6.40
400	600-2600	36-42	2.8	2.09	0.79	3.08
400	600-2600	42-48	2.1	1.01	0.68	2.53
400	600-2600	48-54	2.9	0.96	0.48	1.01
400	600-2600	54-60	1.6	1.63	0.73	2.48

[1] Averages for surface samples from three replicate plots.

[2] Sample hole located on the plot border between nitrogen treatments.

Extractable manganese decreased abruptly below the surface six inches of the waste-treated soil in April 1972 (Table 25), but remained relatively high to a depth of 12 or 24 inches in September 1972 and 1973. This trend is probably related to a decrease in soil pH at these soil depths following the nitrogen fertilizer applications.

Extractable soil copper increased steadily with waste application (Table 24). Copper levels were very low in soil from the check plots: less than 1.0 ppm, whereas Reuther and Labanauskas (1966) report deficiencies at soil levels below 2.0 ppm Cu. No copper deficiency symptoms were observed on plants from the check plots, however, although some plant copper levels were quite low. The copper content of the soil which received 100 tons solid waste per acre remained slightly below 2.0 ppm, but the soil with the higher waste treatments contained adequate levels of copper. In the soils which received 400 tons solid waste per acre, copper levels were high but variable in April 1972 (Appendix Table V-1); the variability may indicate contamination from the blender used to grind the organic waste material included in the soil.

By September 1972, extractable copper levels decreased to less than 10 ppm in soil with the highest waste treatment. Below the surface six inches of soil, the copper content remained less than 2.0 ppm in these soils (Table 25). Apparently the copper added in the waste materials was rapidly immobilized in the soil and could not be readily extracted.

Extractable zinc increased the most dramatically with municipal waste additions, going from 0.4 ppm in soil from the check plots to over 400 ppm in soil from the plots with the highest waste treatment (Table 24). Replicates were quite variable, but the zinc levels did not overlap between waste treatments; each increase in waste application increased the soil zinc content.

The zinc content of the check plots was too low for optimum plant growth: Chapman (1966) sets a critical level of 1.0 ppm Zn for crops in general, but reports deficiencies in wheat and barley grown with 3.5 and 6.6 ppm Zn, respectively. Consequently, the municipal waste treatments had some fertilizer value. With the addition of 100 or 200 tons solid waste per acre, the extractable soil zinc levels increased above deficiency levels but were still not excessive. With 400 tons solid waste per acre, the extractable zinc content increased to a level detrimental to plant growth. Typically a zinc excess induces an iron deficiency chlorosis, but no chlorosis was observed on the plants grown with the highest waste treatment. It is possible that the high levels of iron in the soil balanced zinc uptake.

The neutral to alkaline soil pH and the presence of free lime in the lower horizons probably minimized the toxic effects of high zinc concentration. Zinc is most available in acid soils; as pH increases, zinc is precipitated and becomes unavailable to plants. In addition, zinc is strongly precipitated by lime. In an acid, leached soil the zinc added in waste materials would be a more serious problem.

Excess zinc has often been cited as a major hazard in the land application of sewage materials. In this case, however, the zinc hazard originates in the solid waste materials rather than in the sewage. At the highest rate of waste application approximately 370 lb Zn/acre were added in the solid waste, while only 11 lb Zn/ acre were added in the sewage. The latter figure compares well with the recommended fertilizer rate of 10 lb Zn/acre for this soil. The highest soil zinc levels measured occurred in soils from plots which received solid waste but no sewage (Appendix Table V-1). Apparently the refuse spread on these plots contained more zinc than the average, while the extra addition of zinc in sewage was not significant on the other replicates.

The extractable zinc content of soil on the check plots increased in September 1972, after fertilization with zinc sulfate, but the increase was neither uniform nor pH-dependent (Table 24). The zinc content of soil on the waste-treated plots varied, but did not exceed 100 ppm. Although zinc was rapidly released from the waste materials, it apparently became immobilized almost as rapidly. Continued release, as metal pieces rusted and fragmented, did not greatly affect extractable levels in the soil. In September 1973, the soil from one waste-treated plot contained 145 ppm extractable zinc, while the replicates were much lower. The soil high in zinc also contained an excess of iron; it is possible that a small fragment of galvanized metal was included in the sample. Rusted bits and pieces of metal (and pieces of plastic and rubber) remained on the waste-treated plots after two years, and constitute a long-term source of variability.

Below the surface six inches, the extractable zinc content of the waste-treated soil was very low in April 1972 (Table 25). By September 1972, however, zinc had been leached into the profile of one waste-treated plot: the zinc content of this soil decreased progressively with depth, but exceeded the zinc content of the untreated soil to a depth of 30 inches. In September 1973, increased zinc levels were measured below the surface of both the waste-treated soils which were sampled, in one case extending to a depth of 60 inches.

Plant Uptake of Boron

The boron content of wheat sampled in April 1972 increased dramatically with the addition of municipal wastes (Table 26). Wheat from the check plots contained 4 to 6 ppm B while wheat from plots which received 100 tons solid waste per acre contained about

Table 26. Boron content of wheat, fescue, and alfalfa.[1]

Solid waste ton/acre	Nitrogen added lb/acre	Harvested in 4/72 ppm B	Harvested in 6/72[2] ppm B	Nitrogen added lb/acre	Harvested in 6/72 ppm B	9/72	5/73	7/73	8/73
Wheat					Fescue				
0	80	4.5	4.2	250	3.4	2.2	ns[3]	6.2	ns
0	130	4.6	2.6	500	3.6	2.6	ns	6.8	ns
0	180	6.3	3.2	1000	4.2	2.8	ns	4.4	ns
100	130	20	2.7	500	15	3.5	ns	10.5	ns
100	180	20	3.9	1000	14	3.0	ns	9.9	ns
100	280	26	2.9	2000	8.9	2.6	ns	8.5	ns
200	130	47	3.9	500	11	3.2	ns	7.8	ns
200	180	64	2.6	1000	12	3.0	ns	6.6	ns
200	280	66	6.1	2000	16	3.0	ns	8.9	ns
400	130	70	ns	500	22	3.9	ns	8.4	ns
400	180	95	ns	1000	18	5.5	ns	7.9	ns
400	280	104	ns	2000	37	4.5	ns	9.1	ns
					Alfalfa				
0				80	35	40	45	ns	47
0				200	34	37	38	ns	45
0				400	39	37	40	ns	58
100				200	43	40	40	ns	52
100				400	44	40	38	ns	56
100				600	44	39	37	ns	53
200				200	44	48	45	ns	54
200				400	48	45	33	ns	73
200				600	49	54	32	ns	76
400				200	52	40	45	ns	84
400				400	54	46	41	ns	96
400				600	60	48	44	ns	78

[1] Average of three replicates.

[2] One replicate only.

[3] No sample collected.

20 ppm B, a moderately toxic level. Wheat from plots which received 200 or 400 tons solid waste per acre contained severely toxic levels of boron, up to 100 ppm. Nitrogen fertilization had no consistent effect on boron uptake.

The normal boron content of wheat is 3 to 5 ppm (Sauchelli, 1969); however, Gupta et al. (1973) report few or no visible toxicity symptoms on wheat containing 7 to 8 ppm B, but a moderate degree of brown spot and burn on leaf tips of wheat containing 24 ppm B. Boron toxicity is generally characterized by a yellowing and burning of leaf tips and/or margins (Bradford, 1966). The tip burn observed on wheat plants grown on the waste-treated plots was probably due to an excess of boron rather than, or in combination with, winter frost injury.

In June 1972 wheat from the plots which received the two lower waste treatments contained normal levels of boron, possibly due to a dilution effect with plant maturity. The boron content of fescue harvested in June, however, increased with waste application. The boron requirement and tolerance of fescue is similar to that of wheat, and fescue from the check plots contained a normal 3 to 4 ppm B (Table 26). Fescue grown on the waste-treated plots contained slightly to moderately toxic levels of boron: an average of 13 ppm B with the two lower waste treatments, and 26 ppm B when 400 tons solid waste per acre were applied to the soil. A tip burn was observed on plants grown on the waste-treated plots. By September 1972, after a season of net leaching, the boron content of the fescue from all plots had decreased to normal levels. But with the drier conditions of 1973, boron uptake returned to somewhat higher levels and a tip burn was again observed.

Alfalfa is more boron-tolerant than are wheat and fescue, and normally contains 25 to 40 ppm B (sauchelli, 1969). Bradford (1966) cites values of several hundred ppm boron in leaves of alfalfa grown in sand culture, without visible toxicity symptoms. The boron content of alfalfa harvested in June 1972 increased only slightly with the addition of municipal wastes, reaching an average of 55 ppm in plants from the plots with the highest waste treatment. This is probably not high enough to be detrimental to plant growth. The alfalfa harvested from the waste-treated plots in September 1972 and May 1973 contained normal levels of boron. After the intermittent dry periods of the 1973 season, however, the boron content of the alfalfa was above normal and increased with waste application. The highest boron levels measured (nearly 100 ppm in some alfalfa grown with 400 tons solid waste per acre) may not have been detrimental to alfalfa growth, but they do indicate a continuing potential hazard. All the boron added with the waste materials apparently was not leached from the soil profile, and that which remained could produce toxic effects in boron-sensitive crops, especially under relatively dry conditions.

Soil Boron Content

The soil boron content increased sharply with waste application (Table 27). In April 1972 the check plots contained about 0.6 ppm B, an adequate level for plant growth. A general critical level for boron deficiency has been set at 0.5 ppm B, but 0.4 and 0.3 ppm B have been reported adequate in sandy soils (Bradford, 1966). At the opposite extreme, soil boron levels in excess of 1.5 ppm appear to be unsafe for most crops (Richards, 1954). The boron content of the plots which received 100 tons solid waste per acre slightly exceeded this limit, while those which received 200 tons solid waste per acre contained several times as much boron. Plant toxicity symptoms and excessive boron uptake correlated well with these high soil boron levels. On the plots which received 400 tons solid waste per acre, the soil boron content was extremely high, exceeding 30 ppm. Very few wheat plants were able to grow on these plots and those that did survive contained phytotoxic levels of boron. The extremely high boron content of these plots reflects the fact that very little soil was mixed with the waste materials at the highest rate of waste application. The boron content of the solid waste applied was approximately 55 ppm.

By June 1972 the boron content of the surface soil of the plots

Table 27. Boron content of surface soil (0-6 inches).[1]

Solid waste ton/acre	Nitrogen added lb/acre	Sampled in 4/72 ppm B	Nitrogen added lb/acre	Sampled in 6/72	9/72[2]	3/73	9/73[2]
				---------- ppm B			--------------
	Wheat plots		------------ Fescue plots --------				
0	80	0.54	250	0.36	0.48	0.46	0.43
0	130	0.56	500	0.48	0.40	0.50	0.46
0	180	0.61	1000	0.37	0.21	0.37	0.62
100	130	1.6	500	0.83	0.60	0.64	0.62
100	180	2.0	1000	0.80	0.59	0.70	0.76
100	280	1.8	2000	0.72	0.40	0.74	0.62
200	130	7.4	500	0.95	1.00	0.68	0.74
200	180	4.6	1000	0.96	0.50	0.64	0.65
200	280	5.1	2000	0.74	0.90	0.72	0.72
400	130	36	500	1.33	1.6	2.8	1.4
400	180	31	1000	1.39	2.4	2.6	2.6
400	280	31	2000	1.77	1.7	3.1	1.8
			----------- Alfalfa plots ---------				
0			80	0.43	0.52	0.49	0.46
0			200	0.56	0.54	0.48	0.46
0			400	0.45	0.29	0.45	0.38
100			200	0.69	0.49	0.65	0.50
100			400	0.73	0.71	0.59	0.67
100			600	0.52	0.52	0.54	0.46
200			200	0.99	0.84	0.66	0.60
200			400	1.12	0.71	0.77	0.59
200			600	1.13	0.98	0.90	0.91
400			200	1.89	2.1	3.2	2.1
400			400	2.28	1.7	3.2	2.3
400			600	2.68	2.2	3.6	2.2

[1] Average of three replicates.

[2] One replicate only.

which received 100 or 200 tons solid waste per acre had decreased to 1.0 ppm or less, a safe level for boron-tolerant crops such as alfalfa. Soil boron levels above 0.7 ppm, however, may be toxic to more sensitive crops (Richards, 1954), and toxicity symptoms did appear on the fescue. On the plots which received 100 tons solid waste per acre, the soil boron content fell to about 0.6 ppm in September 1972 and remained at the same level in 1973. With application of 200 tons solid waste per acre, the soil boron level remained slightly high in September 1972, then decreased to 0.7 ppm in 1973. Thus, soil boron content remained toxic to the fescue on these plots, although it fell within an optimum range for alfalfa after the first month or two of irrigation.

The plots which received 400 tons solid waste per acre were plowed to a depth of 12 inches after the April 1972 samples were collected. The resultant mixing of the waste materials with soil, followed by leaching when irrigation was begun in May, caused a considerable decrease in the boron content of the surface soil. Even so, soil boron content remained near or above the critical 1.5 ppm level on these plots in June 1972 (Table 27). Variability between samples was high, due to the heterogenous nature of the waste materials. There was little or no further decrease in soil boron content in September 1972 and there was an increase to about 3.0 ppm B in March 1973. In September 1973 the soil boron content returned to about 2.0 ppm, still above the critical level.

Large amounts of boron were concentrated in the waste materials on the surface of the plots with the highest waste treatment in April 1972, but boron levels were low below a depth of 12 inches (Figure 10). By June, boron levels had decreased in the surface soil but increased to over 2.0 ppm to a depth of 24 inches. In September the soil contained about 1.0 ppm B to a depth of two feet, but increased slightly at three feet in the waste-treated soils. Apparently boron was leached to at least a three-foot depth during the irrigation season. Virtually all of the boron added in the waste materials was water-soluble (Table 9); little, if any, additional boron would be released as the wastes decomposed.

During the winter of 1972-73, boron moved up through the soil profile, increasing the boron content of the surface soil appreciably on the plots with 400 tons solid waste per acre (Table 27; Figure 10d). Soil boron content was high to a depth of over four feet. The extent of downward leaching probably varied with the amount of water applied to a particular area by irrigation, and the subsequent upward movement of boron also varied from plot to plot, resulting in different boron levels at different depths. A weakly cemented caliche layer at a depth of four feet may have acted as a barrier to boron movement in areas where leaching was pronounced. Upward boron movement could have been caused by net evaporation

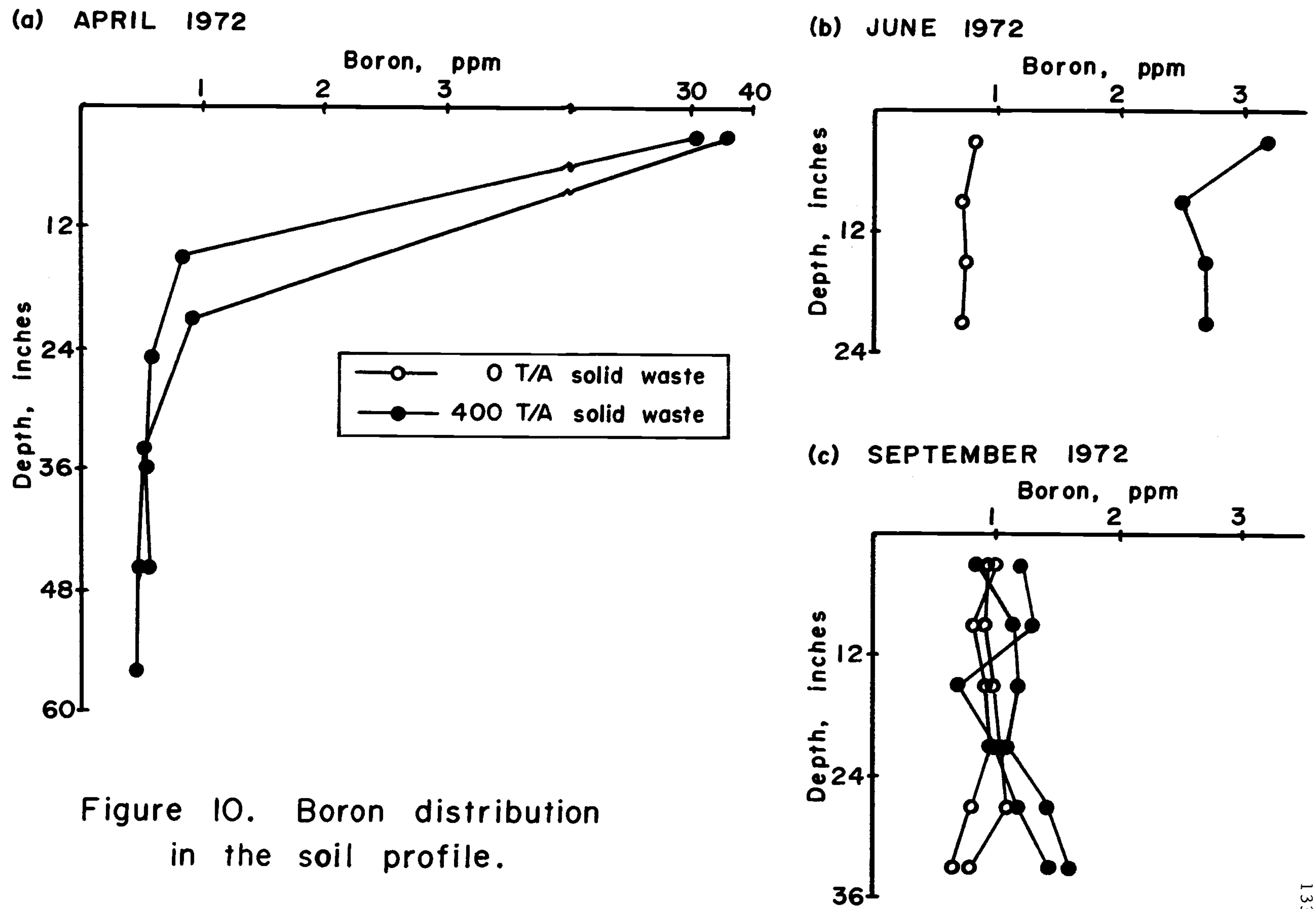


Figure 10. Boron distribution in the soil profile.

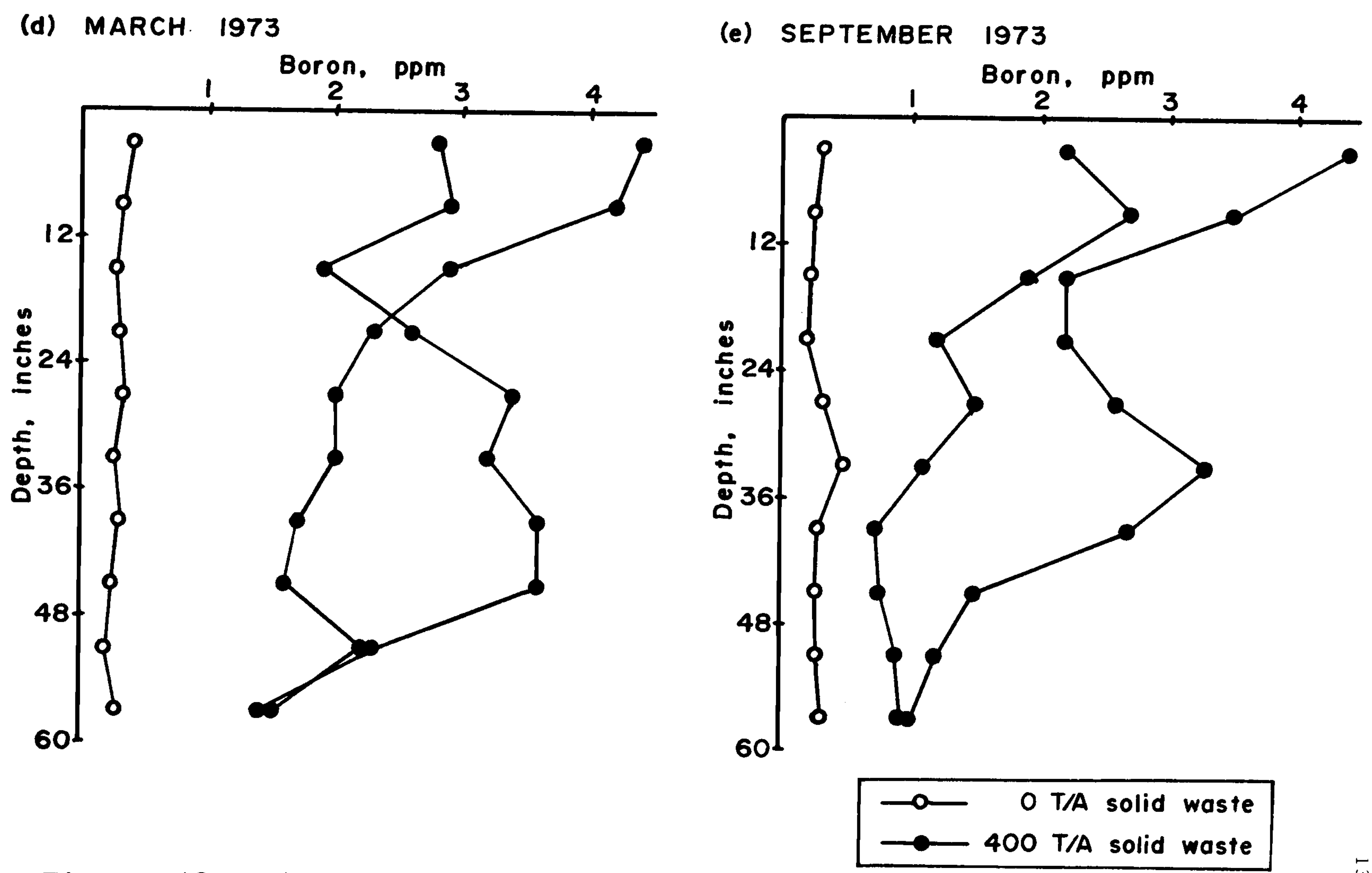


Figure 10. Continued.

after the irrigation system was turned off in the fall. Apparently boron remains largely in soluble form in this soil, and follows water movement patterns.

In September 1973 boron levels remained high (2 to 4 ppm) in the surface soil, decreased somewhat with depth, then increased to a second peak between two and three feet below the soil surface (Figure 10e). This double-peak pattern was probably caused by boron movement downward under irrigation early in the season, followed by movement of some boron back toward the surface during an extended dry period in late July and early August. Subsequent irrigation was not sufficient to move the boron down again, although one soil core shows a decrease in boron at the surface, the beginning of another leaching cycle. The double-peak depth pattern is even more clearly shown in the September 1973 sodium analyses.

In summary, the boron was leached downward into the subsoil with steady over-irrigation during 1972 and moved back upward during the dry periods of winter and periodic interruption of the irrigation regime in 1973. Successful crop production after the addition of solid wastes may depend on consistent over-irrigation to move boron below the rooting zone. Increased boron uptake by both fescue and alfalfa during the dry 1973 season supports the hypothesis of recurrent soil boron toxicity under dry conditions.

It has been noted elsewhere that boron added to the soil in soluble form, whether as fertilizer (Tisdale and Nelson, 1966) or as the result of mineral weathering (Krauskopf, 1972), largely remains soluble and free to migrate with water movement. Some retention by clay minerals and sesquioxides takes place, to a greater degree in alkaline soils than in acid soils. This process would be minimal in the Sagehill soil, however, since the total clay content is less than ten percent. Others have postulated that the addition of calcium to a soil leads to the fixation of boron as precipitated calcium borates or borate complexes (Bradford, 1966; Buckman and Brady, 1969). Since the Sagehill soil contained free calcium carbonate below a depth of 14 inches, the boron released from solid wastes could be immobilized in this manner. The data presented here do not support this hypothesis. At the highest rate of waste application, the approximately 30 ppm of boron concentrated in the upper six inches would be reduced to 3. 0 ppm by uniform distribution of the boron to a depth of 60 inches. Despite sample variability, this agrees reasonably well with actual observations (Figure 10). If calcium borates are formed they appear to remain sufficiently soluble to permit free movement of boron throughout the profile. Neither the fine sandy surface layer nor the silty subsoil retained boron appreciably despite the presence of abundant free calcium.

Sodium

The sodium content of wheat sampled in April 1972 was very low: 0.05 to 0.06%, increasing slightly with the highest rate of waste application (Table 28). By June, however, wheat from all the plots sampled, including the check plots, contained about four times as much sodium as in April. The fescue and alfalfa harvested in June also contained moderately high levels of sodium: 0.4 to 0.6%. Sauchelli (1969) sets a general range for the sodium content of pasture grasses at 0.05 to 1.0%; toxic effects would not be expected within these limits. Accordingly, the tip burn observed on the wheat and fescue plants was probably not due to salt injury.

Alfalfa may exhibit toxicity symptoms at a sodium content of 0.7% (Lunt, 1966). This level was approached or slightly exceeded in the alfalfa harvested in September 1972, but no tip burn or reddening of leaves was observed. The sodium content of the alfalfa decreased in subsequent harvests and was never affected by waste or nitrogen treatments.

The sodium content of the fescue increased slightly with time, but did not exceed acceptable levels. The slow, general increase may have been related to the continued nitrogen fertilizer applications and/or to a general increase in soil sodium content. A clear increase in sodium content with nitrogen application was measured in the

Table 28. Sodium content of wheat, fescue, and alfalfa.[1]

Solid waste ton/acre	Nitrogen added lb/acre	Harvested in 4/72	6/72[2]	Nitrogen added lb/acre	Harvested in 6/72	9/72	5/73	7/73	8/73
		----- % Na-----			------------ % Na ------------				
	Wheat				Fescue				
0	80	0.050	0.20	250	0.41	0.38	ns[3]	0.56	ns
0	130	0.046	0.16	500	0.36	0.54	ns	0.67	ns
0	180	0.055	0.18	1000	0.40	0.66	ns	0.72	ns
100	130	0.053	0.21	500	0.47	0.58	ns	0.70	ns
100	180	0.065	0.20	1000	0.51	0.61	ns	0.64	ns
100	280	0.053	0.24	2000	0.53	0.80	ns	1.03	ns
200	130	0.056	0.25	500	0.48	0.50	ns	0.62	ns
200	180	0.057	0.29	1000	0.42	0.52	ns	0.70	ns
200	280	0.057	0.31	2000	0.59	0.60	ns	0.89	ns
400	130	0.098	ns	500	0.57	0.73	ns	0.58	ns
400	180	0.078	ns	1000	0.64	0.79	ns	0.74	ns
400	280	0.085	ns	2000	0.60	0.65	ns	0.98	ns
					Alfalfa				
0				80	0.41	0.67	0.47	ns	0.065
0				200	0.41	0.76	0.55	ns	0.155
0				400	0.45	0.69	0.56	ns	0.068
100				200	0.47	0.65	0.60	ns	0.095
100				400	0.50	0.67	0.45	ns	0.105
100				600	0.47	0.65	0.49	ns	0.104
200				200	0.38	0.82	0.52	ns	0.099
200				400	0.39	0.68	0.52	ns	0.107
200				600	0.42	0.68	0.47	ns	0.123
400				200	0.39	0.68	0.53	ns	0.118
400				400	0.51	0.81	0.56	ns	0.122
400				600	0.37	0.67	0.55	ns	0.126

[1] Average of three replicates.

[2] One replicate only.

[3] No sample collected.

fescue harvest of July 1973, while there was no consistent trend with waste application. Sauchelli (1969) observed that the sodium content of many grass species is greatly increased by the addition of nitrogen. The nitrogen fertilizer contained only 75 ppm sodium, or about 0.7 lb sodium per 2000 lb nitrogen.

The soil on the check plots contained very little sodium (0.1 me/100g) in April 1972 (Table 29). The sodium content increased with the addition of 100 or 200 tons solid waste per acre, but did not reach unsafe levels. On the plots which received 400 tons solid waste per acre, however, the sodium content rose dramatically to levels of 2 to 4 me/100g. This concentration of sodium in the surface soil could have been injurious to seedlings, but it was apparently balanced by an excess of calcium, so that plant uptake of sodium remained low. Approximately 3 lb sodium and 33 lb calcium were added per ton of solid waste.

By September 1972 the sodium content of the soil which received 400 tons solid waste per acre had decreased to an average of 1.0 me/100g, the sodium level of the untreated soil (Table 29). The soil sodium levels increased with time, reaching an average of 1.5 me/100g in all soils by September 1973. This long-term increase cannot be attributed to sodium added with the waste materials, since it was equally evident on the check plots. However, approximately 900 lb sodium per acre-year were added to the soil in the irrigation

Table 29. Sodium content of surface soil (0-6 inches).

Solid waste ton/acre	Nitrogen added lb/acre	Sampled in 4/72[1] me Na/100g	Nitrogen added lb/acre	Sampled in 9/72[2]	9/73[2]
				---- me Na/100g ---	
	Wheat plots		Fescue plots		
0	80	0.2	250	0.7	1.6
0	130	0.1	500	1.2	1.3
0	180	0.1	1000	1.2	1.6
100	130	0.2	500	1.1	1.6
100	180	0.2	1000	1.0	1.2
100	280	0.2	2000	1.1	1.6
200	130	0.6	500	0.7	1.7
200	180	0.4	1000	0.7	1.2
200	280	0.4	2000	1.0	1.3
400	130	2.8	500	0.8	1.3
400	180	3.8	1000	1.5	2.5
400	280	3.8	2000	0.8	1.1

[1] Average of three replicates.

[2] One replicate only.

water (Table 30). This water was drawn from a deep well adjacent to the plot area.

The irrigation water contained 90 ppm Na and had an electrical conductivity of 0.43 mmho/cm and a sodium adsorption ratio of approximately 8 (Table 30). It falls into a medium-salinity and medium-sodium hazard class (Richards, 1954). Medium-salinity water is considered acceptable for irrigation if a moderate amount of leaching occurs and if the crop is moderately salt tolerant. Medium-sodium water is considered a hazard in fine-textured soils but acceptable for use on coarse soils with good permeability. By

Table 30. Analysis of irrigation water.

pH	7.7
Conductivity, mmho/cm	0.43
Sodium adsorption ratio (SAR)	8
Calcium, ppm	10
Magnesium, ppm	0.73
Potassium, ppm	22
Sodium, ppm	90
Iron, ppm	0.65
Manganese, ppm	0.04
Copper, ppm	<0.01
Zinc, ppm	0.03
Boron, ppm	0.04

these criteria, the water applied should not be hazardous to alfalfa, fescue, or wheat grown on Sagehill sand as long as a policy of over-irrigation is maintained.

Richards (1954) estimates an exchangeable sodium percentage of 9.5 for soil in equilibrium with irrigation water having a sodium adsorption ratio of 8. In September 1973, however, the average sodium content of the surface soil was 1.5 me/100g; with an approximate CEC of 8.5 me/100g, the exchangeable sodium percentage was 18. This exceeds the lower limit of 15% exchangeable sodium for alkali soils, and could constitute a hazard.

The high sodium content of the surface soil in September 1973 is related to the irregular irrigation and consequent dry conditions of that year. Sodium is highly soluble and generally follows water movement patterns, especially in soil with a low CEC. The sodium content of the subsoil was very low in April 1972 (Figure 11). By September, excess sodium had been leached from the surface of the plots which received 400 tons solid waste per acre, and an equilibrium content of approximately 0.5 me Na/100g had been established to a depth of three feet in both the check and the waste-treated soils. In September 1973, however, upward movement of water with net evaporation had increased the surface sodium content to high levels. The sodium content was also greater than 1.0 me/100g at a depth of two to three feet on two plots sampled, creating a double-peak pattern indicative of alternate wetting and drying cycles. With adequate irrigation, sodium levels would probably have remained relatively low and uniform with depth, to the depth of normal water penetration.

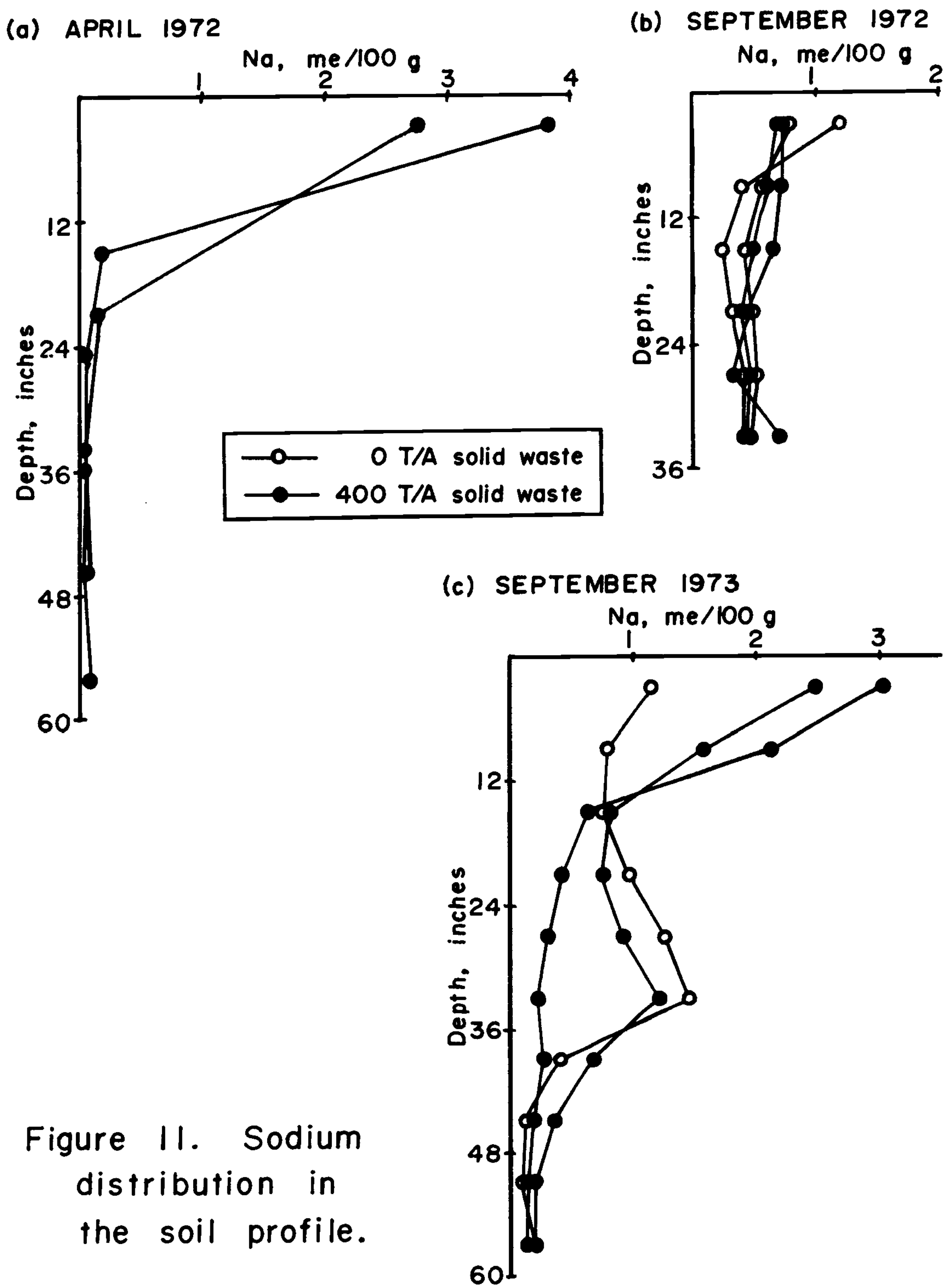


Figure 11. Sodium distribution in the soil profile.

Molybdenum

Molybdenum uptake by wheat and fescue in 1972 increased only slightly with the addition of municipal wastes, but uptake by alfalfa doubled with each increase in waste application (Table 31). Legumes generally take up more molybdenum when it is available in the soil than do other plants; this is probably related to the need for molybdenum for nitrogen fixation by the nodule bacteria associated with legume roots. All plants, however, require molybdenum in small amounts. Johnson (1966) sets a general plant deficiency level at less than 0.1 ppm Mo, but also reports alfalfa leaves deficient at 0.28 ppm Mo and normal at 0.30 ppm or more. The wheat and fescue from all plots and the alfalfa from the check plots contained adequate, generally low levels of molybdenum, ranging from 0.5 to 2.0 ppm.

The higher molybdenum content of the alfalfa from the waste-treated plots is not of concern from the standpoint of plant nutrition. Normal alfalfa growth has been reported when the plants contained 34 ppm Mo (Dye, 1962) and over 200 ppm (Kubota et al., 1961). These values far exceed the molybdenum content of alfalfa from the plots which received the highest waste treatment. Johnson (1966) confirms that plants may contain several hundred ppm molybdenum without injury; he cites only isolated reports of foliar symptoms at

Table 31. Molybdenum content of wheat, fescue, and alfalfa.[1]

Solid waste ton/acre	Nitrogen added lb/acre	Harvested in 4/72	Harvested in 6/72[2]	Nitrogen added lb/acre	Harvested in 6/72	Harvested in 5/73	Harvested in 7/73
		ppm Mo	ppm Mo		ppm Mo	ppm Mo	ppm Mo
	Wheat			Fescue			
0	80	0.6	0.2	250	1.1	ns[3]	1.4
0	130	0.5	0.7	500	1.0	ns	1.1
0	180	0.5	0.4	1000	0.4	ns	0.7
100	130	1.1	1.8	500	1.5	ns	2.4
100	180	0.7	1.4	1000	1.0	ns	1.7
100	280	0.8	0.7	2000	0.8	ns	0.5
200	130	1.2	0.8	500	1.4	ns	1.7
200	180	0.9	1.2	1000	1.0	ns	0.9
200	280	1.0	0.8	2000	0.8	ns	0.5
400	130	1.3	ns	500	1.2	ns	2.3
400	180	1.3	ns	1000	2.0	ns	2.1
400	280	1.8	ns	2000	1.3	ns	1.0
				Alfalfa			
0				80	2.0	0.6	ns
0				200	1.7	0.6	ns
0				400	1.2	0.5	ns
100				200	3.6	1.1	ns
100				400	1.9	1.1	ns
100				600	2.4	1.2	ns
200				200	6.2	1.2	ns
200				400	5.0	1.0	ns
200				600	4.8	1.0	ns
400				200	13.4	1.9	ns
400				400	10.8	1.8	ns
400				600	10.5	2.0	ns

[1] Average of three replicates.

[2] One replicate only.

[3] No sample collected.

molybdenum levels of 1000 to 2000 ppm.

High molybdenum levels in forage crops, however, can lead to an imbalance of molybdenum and copper in livestock, inducing a copper deficiency disease ("scouring" or "teart" disease). Sauchelli (1969) sets a general critical level for molybdenum toxicity to livestock at 5 to 10 ppm Mo in their feed. Dye (1962) found molybdenum toxic to cattle at levels above 5 to 6 ppm, and to sheep at levels above 10 to 12 ppm. By these criteria, the alfalfa from the plots which received 100 tons solid waste per acre should be safe for livestock feed, the alfalfa grown with 200 tons solid waste per acre should be safe for sheep but marginal for cattle, and the alfalfa grown with 400 tons solid waste per acre should be generally toxic if no other feed source is utilized.

Miltimore et al. (1964) found scouring in cattle on forage containing 4.2 or more ppm Mo, but no scouring on forage with 2.2 ppm Mo. However, they felt that the ratio of copper to molybdenum in the forage was a better indicator than the molybdenum content alone. That is, with higher copper levels in the forage, higher molybdenum levels could be tolerated. Severe scouring occurred in cattle on forage with a Cu/Mo ratio of 1.0, less scouring with a ratio of 2.3, and no scouring with a ratio of 4.3. In a later report, Miltimore and Mason (1971) confirmed this hypothesis and set a critical level of 2.0 for the Cu/Mo ratio of cattle forage. The Cu/Mo ratio of alfalfa grown with 200 tons of solid waste per acre was slightly above this level and hence marginally safe (Table 32), while the Cu/Mo ratio of alfalfa grown with 400 tons solid waste per acre was below 2.0 and could have toxic effects.

By 1973, the molybdenum content of alfalfa from all the waste-treated plots had decreased to safe levels (Table 31), although there remained a slight increase with waste treatments. Apparently the molybdenum added in the waste materials had become immobilized in the soil and was no longer easily available to the plants.

Uptake of molybdenum by the fescue remained relatively low in 1973 and was not affected by the waste treatments, but decreased with nitrogen fertilizer applications. This decrease may have been due to a dilution effect as yields increased with nitrogen fertilization, or to the addition of nitrogen *per se*. Barstad (1951) found that the molybdenum content of pasture plants decreased when nitrogen was added although the soil pH was held constant and yields and the level of water soluble soil molybdenum were unaffected. He also found that the addition of sulfate had no effect on plant molybdenum content.

The Cu/Mo ratio of fescue harvested in 1973 increased with increasing nitrogen fertilization, as molybdenum uptake

Table 32. Copper/molybdenum ratio in wheat, fescue, and alfalfa.

Solid waste ton/acre	Nitrogen added lb/acre	Harvested in 4/72 Cu/Mo ratio	Nitrogen added lb/acre	Harvested in 6/72	5/73	7/73
				--------- Cu/Mo ratio		------
	-----Wheat ------		---------- Fescue ------------			
0	0	8.3	250	10	ns[1]	5.7
0	130	10	500	9	ns	7.3
0	180	18	1000	32	ns	13
100	130	8.2	500	12	ns	3.3
100	180	5.7	1000	14	ns	5.9
100	280	7.5	2000	18	ns	24
200	130	9.2	500	11	ns	5.9
200	180	8.9	1000	15	ns	12
200	280	13	2000	18	ns	20
400	130	4.6	500	12	ns	3.9
400	180	6.2	1000	10	ns	8.6
400	280	7.8	2000	19	ns	12
			---------- Alfalfa ----------			
0			80	9.5	22	ns
0			200	6.5	20	ns
0			400	12.5	28	ns
100			200	4.7	14	ns
100			400	12.6	13	ns
100			600	5.4	9	ns
200			200	2.6	11	ns
200			400	2.8	13	ns
200			600	2.1	11	ns
400			200	1.0	4.7	ns
400			400	1.9	6.1	ns
400			600	1.8	5.5	ns

[1] No sample collected.

decreased (Table 32). At the lowest rate of nitrogen application Cu/Mo ratios were still above the critical level, so that the fescue from all plots should be safe for livestock feed. The Cu/Mo ratio of alfalfa from the check plots was quite high in 1973; it decreased with increasing waste treatments, but remained within safe levels even on the plots which received 400 tons solid waste per acre.

Cobalt and Chromium

The cobalt content of wheat, fescue, and alfalfa ranged from 0. 4 to 0. 7 ppm (Table 33) with slightly higher values following two treatments. Uptake by alfalfa from the plots which received 400 tons solid waste per acre increased to about 0. 9 ppm Co in 1972; and uptake by fescue grown with 2000 lb nitrogen per pound increased to about 0. 8 ppm Co in 1972 and 0. 96 ppm Co in 1973. These levels of cobalt have not been shown to be toxic to plants or animals. Vanselow (1966) cites normal levels of 0. 02 to 0. 29 ppm Co in alfalfa, fescue, and wheat but also reports as much as 3. 75 ppm Co in grasses, with no evidence of toxicity. Hunter and Vergnano (1953) and Wallace and Mueller (1973) reported normal growth of oat and bean plants, respectively, which contained 0. 8 ppm Co;

Table 33. Cobalt content of wheat, fescue, and alfalfa.[1]

Solid waste ton/acre	Nitrogen added lb/acre	Harvested in 4/72	Harvested in 6/72[2]	Nitrogen added lb/acre	Harvested in 6/72	Harvested in 5/73	Harvested in 7/73
		---- ppm Co ----			-------- ppm Co --------		
	-------- Wheat --------			----------- Fescue --------			
0	80	0.58	0.31	250	0.38	ns[3]	0.42
0	130	0.50	0.40	500	0.62	ns	0.57
0	180	0.60	0.32	1000	0.71	ns	0.67
100	130	0.37	0.36	500	0.53	ns	0.39
100	180	0.40	0.32	1000	0.54	ns	0.72
100	280	0.51	0.40	2000	0.85	ns	0.96
200	130	0.56	0.47	500	0.69	ns	0.46
200	180	0.53	0.51	1000	0.59	ns	0.58
200	280	0.44	0.43	2000	0.79	ns	0.91
400	130	0.60	ns	500	0.55	ns	0.48
400	180	0.58	ns	1000	0.53	ns	0.78
400	280	0.52	ns	2000	0.79	ns	0.99
				--------- Alfalfa ---------			
0				80	0.65	0.60	ns
0				200	0.69	0.48	ns
0				400	0.65	0.58	ns
100				200	0.67	0.51	ns
100				400	0.76	0.44	ns
100				600	0.62	0.51	ns
200				200	0.71	0.64	ns
200				400	0.79	0.36	ns
200				600	0.68	0.50	ns
400				200	0.85	0.47	ns
400				400	0.89	0.59	ns
400				600	0.93	0.57	ns

[1] Average of three replicates.

[2] One replicate only.

[3] No sample collected.

toxic effects were observed only when plant cobalt levels exceeded 50 ppm.

Cobalt has not been shown to be essential to higher plants, but it is required by Rhizobium, the symbiotic nitrogen-fixing bacteria of legume root nodules (Ahmed and Evans, 1961). These authors found that a concentration of 0.03 or more ppm cobalt in soybeans correlated with normal growth when no combined nitrogen was provided, while plants with 0.02 ppm Co were extremely nitrogen deficient.

Low cobalt levels in forage crops can result in a cobalt deficiency ("pining") in livestock. A critical level of about 0.05 ppm Co in forage has been set by Beeson and Thacker (1958) for cattle and by Mitchell (1945) for sheep. The cobalt levels of plants from the check plots as well as the waste-treated plots were well above this limit.

The chromium content of fescue harvested in 1972 ranged from 0.4 to 0.8 ppm, with no consistent relation to waste or nitrogen treatments (Table 34). The chromium content of alfalfa from the check plots and the plots with the two lower waste treatments fell within the same range, but alfalfa from the plots which received 400 tons solid waste per acre contained an average of 1.0 ppm Cr.

Table 34. Chromium content of fescue and alfalfa.[1]

Solid waste ton/acre	Nitrogen added lb/acre	Harvested 6/72 ppm Cr	Nitrogen added lb/acre	Harvested 6/72 ppm Cr
	Fescue		Alfalfa	
0	250	0.43	80	0.80
0	500	0.82	200	0.58
0	1000	0.60	400	0.54
100	500	0.70	200	0.58
100	1000	0.80	400	0.73
100	2000	0.71	600	0.56
200	500	0.52	200	0.75
200	1000	0.83	400	0.52
200	2000	0.48	600	0.64
400	500	0.47	200	0.75
400	1000	0.62	400	1.41
400	2000	0.56	600	0.92

[1] Average of three replicates.

Pratt (1966) cited normal levels of 4 to 6 ppm Cr in wheat leaves, but Hunter and Vergnano (1953) reported normal growth of oat plants which contained 0.4 ppm Cr and slight chlorosis at 1 to 4 ppm Cr. Soane and Saunder (1959) reported normal growth of maize and tobacco which contained 4 ppm Cr, but noted that the chromium content of leaves did not necessarily increase when toxic concentrations of chromium were applied to the plants. The concentration of chromium in the roots increased dramatically, however, and severe root damage was observed. Apparently excess chromium is retained by plant roots rather than distributed throughout the plant.

Hence, the chromium content of the fescue and alfalfa plant tops does not serve as a good indicator of possible toxic conditions. The chromium added to the soil with 400 tons solid waste per acre (approximately 16 lb Cr/acre) could be sufficient to affect plant growth if it were all in available form. This would be 8 ppm Cr in the soil; Soane and Saunder (1959) found severe stunting and root damage when 10 ppm Cr were applied to a sand culture.

SUMMARY AND CONCLUSIONS

Waste Disposal

Disposal of solid municipal waste by incorporation into sandy soil at rates of 100, 200, and 400 tons per acre was partially successful. Most of the organic waste materials decomposed rapidly after they were incorporated into the sandy soil. Thorough mixing with the soil, adequate moisture, and warm temperatures hastened the decomposition process, so that only an unidentifiable organic residue remained in the soil after one growing season. Metals were oxidized more slowly, and some resistant organic materials (plastics and rubber) were not appreciably altered after two years. These materials cannot readily be disposed of by this method, and should be removed and handled separately. Metals constitute a particular hazard if the soil is cropped: they could damage farm machinery or be ingested by livestock, causing serious injury. Glass caused no problem in the field, since it was shattered to sand-sized particles and became indistinguishable from the soil matrix.

Ground water pollution from the waste materials was not a problem in the experimental area, since insufficient irrigation water was applied to leach chemicals to the water table. In areas of high rainfall, boron would be rapidly leached from the solid waste, but boron has not been identified as a hazardous pollutant. Nitrogen and phosphorous could be leached if they were not first immobilized by micro-organisms engaged in solid waste decomposition.

Heavy metals such as zinc and manganese, although initially available to plants from the wastes, were relatively immobile in the soil. Under acid conditions, however, somewhat greater mobility could be expected.

The rapid decomposition of the bulk of the waste materials prevented the development of any obvious health hazards such as fly infestations. Exposure to the soil and to the activity of antagonistic micro-organisms probably destroyed most pathogenic bacteria, but no tests were made to determine survival percentages.

Crop Production

The application of solid municipal waste at rates up to 200 tons per acre (approximately 133 tons dry matter per acre) did not decrease forage crop yields appreciably, but neither did it increase yields or improve the nutrient quality of the forage. Some beneficial fertilizer effect was obtained from the phosphorus, zinc, and copper in the waste materials. But quantities of boron detrimental to plant growth were also added at all rates of solid waste application.

With the addition of 400 tons solid waste per acre, good forage stands were not obtained because of inadequate seedbed preparation. More thorough grinding of the solid waste and deeper incorporation into the soil would improve the seedbed, so that seed placement could be controlled and germination could be enhanced. Micronutrient levels, however, could prove detrimental to plant growth. Large quantities of zinc, copper, boron, and sodium were added to the soil with 400 tons solid waste per acre, and zinc and boron uptake by wheat and fescue approached or exceeded toxic levels during the first growing season. Sufficient molybdenum was added to increase uptake by the alfalfa to levels hazardous to livestock.

The addition of trace elements in the sewage materials was insignificant compared to those introduced in the solid waste, and insufficient alone to cause any plant problems.

Trace element toxicities diminished by the end of the first growing season, with the exception of boron, which remained in available form at levels detrimental to sensitive crops even on the soil which received the lower waste treatments. Heavy metals such as zinc, copper, manganese, and molybdenum were apparently immobilized in the soil, while excess sodium was leached from the surface and distributed throughout the soil profile. Zinc and manganese uptake by the fescue remained high only where the soil pH had decreased to less than 6.0 following heavy applications of ammonium sulfate. Continued zinc and manganese toxicity could be a problem in acid soils.

Crop production on Sagehill sand after the incorporation of up to 200 tons solid waste per acre is feasible if the boron problem can be minimized or overcome. Use of a boron-tolerant crop such as alfalfa, and the application of sufficient irrigation water to leach the boron beyond the main rooting zone, would be recommended. Yields cannot be expected to exceed those produced on untreated soil, however; the economic benefit must come from the successful disposal of the solid municipal waste.

Further Study

Long-term monitoring of crops grown on the waste-treated soil, with particular attention to micronutrient and trace metal uptake, would provide a better basis for evaluating potential plant toxicities. The accumulation of heavy metals such as chromium, nickel, and cadmium in the soil following waste additions should be investigated, especially if repeated waste applications were made.

Factors affecting boron movement in the soil would be of practical interest for crop management in areas where the boron is not leached from the soil profile. For areas of higher rainfall, possible detrimental effects of high boron concentrations in leachate waters should be considered.

The decomposition or partial decomposition of some plastics included in the solid waste may release toxic organic compounds such as polychlorinated biphenyls (PCB). Some of these compounds are highly toxic to animals and humans in extremely small concentrations. Such compounds may be promptly decomposed further in the soil; but if not, they could contaminate run-off or ground waters or they could accumulate in the soil and endanger microbial life and/or grazing livestock.

BIBLIOGRAPHY

1. Advisory Committee on Environmental Science and Technology. 1971. Environmental quality in Oregon 1971. Environ. Sci. Inf. Coord., Oregon State Univ., Corvallis, Oregon.

2. Ahmed, S., and H. J. Evans. 1961. The essentiality of cobalt for soybean plants grown under symbiotic conditions. Proc. Nat. Acad. Sci. USA 47:24-36.

3. American Public Works Association. 1966. Municipal refuse disposal. Publ. Admin. Serv., Chicago, Ill.

4. Andersson, A. and K. O. Nilsson. 1972. Enrichment of trace elements from sewage sludge fertilizer in soils and plants. AMBIO 1(5):176-179.

5. Antonovics, J., A. D. Bradshaw, and R. G. Turner. 1971. Heavy metal tolerances in plants. Adv. Ecol. Res. 7:1-85.

6. Barshad, I. 1951. Factors affecting the molybdenum content of pasture plants: II. Effect of soluble phosphates, available nitrogen, and soluble sulfates. Soil Sci. 71:387-398.

7. Beeson, K. C., and E. J. Thacker. 1958. Occurrence of mineral deficiencies and toxicities in animals in the United States and problems of their detection. Soil Sci. 85:87-94.

8. Bengston, G. W., and J. J. Cornette. 1973. Disposal of composted municipal waste in a plantation of young slash pine: Effects on soil and trees. J. Environ. Qual. 2:441-444.

9. Berrow, M. L., and J. Webber. 1972. Trace elements in sewage sludges. J. Sci. Fd. Agric. 23:93-100.

10. Black, C. A. (ed). 1965. Methods of soil analysis: Part II: Chemical and microbial analysis. Amer. Soc. Agron., Madison, Wisc.

11. Bradford, G. R. 1966. Boron. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

12. Buckman, H. O., and N. C. Brady. 1969. The nature and properties of soils. 7th ed. Macmillan, New York, N. Y.

13. Carlson, C. W., and J. D. Menzies. 1971. Utilization of urban wastes in crop production. BioScience 21:561-564.

14. Chapman, H. D. (ed). 1966. Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

15. Chapman, H. D. 1966. Calcium. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

16. Chapman, H. D. 1966. Zinc. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

17. Council on Environmental Quality, Executive Office of the President. 1970. The first annual environmental quality report. US Government Printing Office, Wash., D. C.

18. Day, A. D., and R. M. Kirkpatrick. 1973. Effects of treated municipal wastewater on oat forage and grain. J. Environ. Qual. 2:282-284.

19. Day, A. D., A. Rahman, F.R.H. Katterman, and V. Jenson. 1974. Effects of treated municipal wastewater and commercial fertilizer on growth, fiber, acid-soluble nucleotides, protein, and amino acid content in wheat hay. J. Environ. Qual. 3:17-19.

20. Day, A. D., J. L. Stroehlein, and T. C. Tucker. 1972. Effects of treatment plant effluent on soil properties. J. Water Pollut. Contr. Fed. 44(3):372-375.

21. Dobson, A. L., and H. A. Wilson. 1963. Refuse decomposition in strip mine spoils. Proc. W. Va. Acad. Sci. 35:59.

22. Duggan, J. C. 1973. Utilization of municipal refuse compost: I. Field-scale compost demonstrations. Compost Sci. 14(2): 24-25.

23. Duggan, J. C. and D. H. Scanlon. 1974. Evaluation of municipal refuse compost for ash pond stabilization. Compost Sci. 15(1):26-30.

24. Dye, W. B. 1962. A micronutrient survey of Nevada forage. Nev. Agr. Exp. Sta. Tech. Bull. No. 227.

25. Eaton, F. M. 1966. Sulfur. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

26. Embleton, T. W. 1966. Magnesium. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

27. Fuller, W. H., G. Johnson, and G. Sposito. 1960. Influence of municipal refuse compost on plant growth. Compost Sci. 1(3):16-19.

28. Galler, W. S. and L. J. Partridge. 1969. Physical and chemical analysis of domestic municipal refuse from Raleigh, North Carolina. Compost Sci 10(3):12-15.

29. Gupta, U. C. 1972. Effects of manganese and lime on yield and on the concentration of Mn, Mo, B, Cu, and Fe in the boot stage tissue of barley. Soil Sci. 114:131-136.

30. Gupta, U. C., J. D. E. Sterling, and H. G. Nass. 1973. Influence of various rates of compost and nitrogen on the boron toxicity symptoms in barley and wheat. Can. J. Plant Sci. 53:451-456.

31. Hart, S. A., W. J. Flocker, and G. K. York. 1970. Refuse stabilization in the land. Compost Sci. 11(1):4-8.

32. Henning, S. and T. L. Jackson. 1973. Determination of molybdenum in plant tissue using flameless atomic absorption. Atomic Abs. News. 12(4):100-101.

33. Herbert, W. and W. A. Flower. 1971. Waste processing complex emphasizes recycling. Publ. Works 102(6):78-81.

34. Hinesly, T. D., O. C. Braids, and J. E. Molina. 1971. Agricultural benefits and environmental changes resulting from the use of digested sewage sludge on field crops. Interim report on a solid waste demonstration project, US Environ. Prot. Agency, SW-30d, Urbana-Champaign, Ill.

35. Hinesly, T. D., R. L. Jones, and B. Sosewitz. 1972. Use of waste treatment plant solids for mined land reclamation. Mining Congr. J. 58:66-73.

36. Hinesly, T. D., R. L. Jones, and E. L. Ziegler. 1972. Effects on corn by application of heated anaerobically digested sludge. Compost Sci. 13:26-30.

37. Hortenstine, C. C. and D. F. Rothwell. 1969. Evaluation of composted municipal refuse as a plant nutrient source and soil amendment on Leon fine sand. Soil & Crop Sci. Soc. Florida Proc. 29:312-319.

38. Hortenstine, C. C. and D. F. Rothwell. 1972. Use of municipal compost in reclamation of phosphate-mining sand tailings. J. Environ. Qual. 1:415-418.

39. Hortenstine, C. C. and D. F. Rothwell. 1973. Pelletized municipal refuse compost as a soil amendment and nutrient source for sorghum. J. Environ. Qual. 2:343-345.

40. Hunt, P. G., C. C. Hortenstine, and C. F. Eno. 1973. Direct and indirect effects of composted municipal refuse on plant seed germination. Soil & Crop Sci. Soc. Florida Proc. 32:92-95.

41. Hunt, P. G., C. C. Hortenstine, and G. C. Smart. 1973. Responses of plant parasitic and saprophytic nematode populations to composted municipal refuse. J. Environ. Qual. 2: 264-266.

42. Hunt, P. G., G. C. Smart, and C. F. Eno. 1973. Sting nematode, Belonolaimus longicaudatus, immotility induced by extracts of composted municipal refuse. J. Nematol. 5(1): 60-63.

43. Hunter, J. G. and O. Vergnano. 1953. Trace-element toxicities in oat plants. Ann. Appl. Biol. 40:761-777.

44. Jackson, M. L. 1958. Soil chemical analysis. Prentice Hall, Englewood Cliffs, N. J.

45. Johnson, C. M. 1966. Molybdenum. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

46. Kaiser, E. R. 1966. Chemical analysis of refuse components. Proc. Nat. Incinerator Conf., ASME, New York, pp. 84-88.

47. Kardos, L. T. 1970. A new prospect. Environ. 12(2):10-27.

48. King, L. D. and H. D. Morris. 1972a. Land disposal of liquid sewage sludge: I. The effect on yield, in vivo digestibility, and chemical composition of coastal Bermudagrass (Cynodon dactylon L. Pers.). J. Environ. Qual. 1:325-329.

49. King, L. D. and H. D. Morris. 1972b. Land disposal of liquid sewage sludge: II. The effect on soil pH, Mn, Zn, and growth and chemical composition of rye (Secale cereale L.). J. Environ. Qual. 1:425-429.

50. King, L. D., L. A. Rudgers, and L. R. Webber. 1974. Application of municipal refuse and liquid sewage sludge to agricultural land: I. Field study. J. Environ. Qual. 3: 361-366.

51. Kubota, J., V. A. Lazar, L. N. Langan, and K. C. Beeson. 1961. The relationship of soils to molybdenum toxicity in cattle in Nevada. Soil Sci. Soc. Amer. Proc. 25:227-232.

52. Labanauskas, C. K. 1966. Manganese. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. of Calif., Riverside, Calif.

53. Le Riche, H. H. 1968. Metal contamination of soil in the Woburn market-garden experiment resulting from the application of sewage sludge. J. Agr. Sci. Camb. 71:205-208.

54. Lunt, H. A. 1959. Digested sewage sludge for soil improvement. Conn. Agr. Exp. Sta. Bull. No. 622.

55. Lune, O. R. 1966. Sodium. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

56. Mays, D. A., G. L. Terman, and J. C. Duggan. 1973. Municipal compost: Effects on crop yields and soil properties. J. Environ. Qual. 2:89-92.

57. Miltimore, J. E. and J. L. Mason. 1971. Copper to molybdenum ratio and molybdenum and copper concentrations in ruminant feeds. Can. J. Animal Sci. 51:193-200.

58. Miltimore, J. E., J. L. Mason, J. M. McArthur, and R. B. Carson. 1964. Ruminant mineral nutrition. The effect of copper injections on weight gains and haemoglobin levels of cattle pastured on ground-water soils in the British Columbia interior. Can. J. Comp. Med. Vet. Sci. 28:108-112.

59. Mitchell, R. L. 1945. Copper and nickel in soils and plants. Soil Sci. 60:63-70.

60. Molina, J. A. E., O. C. Braids, T. D. Hinesly, and J. B. Cropper. 1971. Aeration-induced changes in liquid digested sewage sludge. Soil Sci. Soc. Amer. Proc. 35:60-63.

61. Mortvedt, J. J., P. M. Giordano and W. L. Lindsay. 1972. Micronutrients in agriculture. Soil Sci. Soc. Amer., Madison, Wisc.

62. Page, A. L. 1973. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. A literature review study prepared for the Ultimate Disposal Research Program, Environ. Prot. Agency, Cincinnati, Ohio.

63. Patterson, J. B. E. 1971. Metal toxicity arising from industry. Tech. Bull., Min. Agr. Fisheries & Food 21:193-207.

64. Perkin-Elmer Corporation. 1971. Analytical methods for atomic absorption spectrophotometry. Perkin-Elmer Corp., Norwalk, Conn.

65. Pramer, D. and E. L. Schmidt. 1964. Experimental soil microbiology. Burgess, Minneapolis, Minn.

66. Pratt, P. F. 1966. Chromium. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

67. Pratt, P. F., F. E Broadbent, and J. P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agr.,

June 1973, 10-13.

68. Pringle, W. L., W. K. Dawley, and J. E. Miltimore. 1973. Sufficiency of copper and zinc in barley forage and corn silage rations as measured by response to supplements by beef cattle. Can. J. Animal Sci. 53(3):497-502.

69. Purves, D. 1972. Consequences of trace-element contamination of soils. Environ. Pollut. 3:17-24.

70. Purves, D. and E. J. MacKenzie. 1970. Enhancement of trace-element content of cabbages grown in urban areas. Plant Soil 33:483-485.

71. Purves, D. and E. J. MacKenzie. 1973. Effects of application of municipal compost on uptake of copper, zinc, and boron by garden vegetables. Plant Soil 39:361-371.

72. Purves, D. and E. J. MacKenzie. 1974. Phytotoxicity due to boron in municipal compost. Plant Soil 40:231-235.

73. Rehling, C. J. and E. Truog. 1940. "Milorganite" as a source of minor elements for plants. J. Amer. Soc. Agron. 32: 894-906.

74. Reuther, W. and C. K. Labanauskas. 1966. Copper. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

75. Richards, L. A. (ed). 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook No. 60.

76. Roberts, S., R. V. Vodraska, M. D. Kauffman, and E. H. Gardner. 1971. Methods of soil analysis used in the Soil Testing Laboratory at Oregon State University. OSU Agr. Exp. Sta. Special Report No. 321.

77. Rogus, C. A. 1964. Refuse quantities and characteristics. Amer. Publ. Works Asso. Special Report No. 29:17-27.

78. Rohde, G. 1962. The effects of trace elements on the exhaustion of sewage-irrigated land. Inst. Sewage Purifi., London, J. & Proc. pp. 581-585.

79. Rothwell, D. F. and C. C. Hortenstine, 1969. Composted municipal refuse: Its effects on carbon dioxide, nitrate, fungi, and bacteria in Arrendondo fine sand. Agron. J. 61:837-840.

80. Sauchelli, V. 1969. Trace elements in agriculture. Van Nostrand Reinhold. New York, N. Y.

81. Scanlon D. H., J. C. Duggan, and S. D. Bean. 1973. Evaluation of municipal compost for strip mine reclamation. Compost Sci. 14(3):4-8.

82. Soane, B. D. and D. H. Saunder. 1959. Nickel and chromium toxicity of serpentine soils in Southern Rhodesia. Soil Sci. 88:322-330.

83. Sopper, W. E. 1972. Municipal wastewater aids revegetation of strip-mined spoil banks. J. For. 70:612-615.

84. Sutton, P. and J. P. Vimmerstedt. 1974. Treat stripmine spoils with sewage sludge. Compost Sci. 15(1):22-23.

85. Terman, G. L., J. M. Soileau, and S. E. Allen. 1973. Municipal waste compost: Effects on crop yields and nutrient content in greenhouse pot experiments. J. Environ. Qual. 2: 84-89.

86. Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and Fertilizers. 2nd. ed. Macmillan, New York, N.Y.

87. Thomas, R. E., W. A. Schwartz, and T. W. Bendixen. 1966. Soil chemical changes and infiltration rate reduction under sewage spreading. Soil Sci. Soc. Amer. Proc. 30:641-646.

88. USDA, Soil Survey Staff. 1962. Soil survey manual. USDA Handbook No. 18.

89. Ulrich, A. and K. Ohki. 1966. Potassium. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

90. Vanselow, A. P. 1966. Cobalt. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

91. Volk, B. G., G. H. Snyder, G. J. Gascho, and P. H. Henderson. 1973. Cropland disposal of hydropulped municipal refuse. 1. A greenhouse and growth chamber evaluation. Soil & Crop Sci. Soc. Florida Proc. 32:95-99.

92. Volk, V. V. and C. H. Ullery. 1972. Disposal of municipal wastes on sandy soil: A report to The Boeing Company, Sept. 1971 - Sept. 1972. Dept. of Soil Sci., OSU, Corvallis, Ore.

93. Wallace, A. and R. T. Mueller. 1973. Effects of chelated and nonchelated cobalt and copper on yields and microelement composition of bush beans grown on calcareous soil in a glasshouse. Soil Sci. Soc. Amer. Proc. 37:907-908.

94. Wallihan, E. F. 1966. Iron. In: Chapman, H. D. (ed). Diagnostic criteria for plants and soils. Univ. Calif., Riverside, Calif.

95. White, R. P. 1970. Effects of lime upon soil and plant manganese levels in an acid soil. Soil Sci. Soc. Amer. Proc. 34:625-629.

96. Woods, C. 1973. One man's garbage may become another man's timber. Sunshine State Agr. Res. Rep. May-June 1973, Univ. Fla., Gainesville, Fla.

APPENDICES

APPENDIX I

I-1. Soil Description

Described:	May 1972, by N. Cottrell and G. Halvorson.
Location:	Morrow County, Oregon, about ten miles southwest of Boardman; center of section 25, T3N, R23E, Willamette Meridian.
Elevation:	600 feet.
Landform:	Plateau above the Columbia River.
Slope:	Level or gently sloping, with some hummocky patches.
Parent Material:	Fine sand, probably wind-deposited, overlying silt.
Drainage:	Well drained; water table is deep.
Climate:	7-9 inches annual precipitation; mean annual temperature 53^{o}F.
Vegetation:	Bunch grasses, cheat grass Russian thistle, rabbit-brush, sagebrush.
Human influence:	Tillage and surface incorporation of municipal wastes (to an eight-inch depth) on experimental plots.

Typical profile described 5/19/72; located 40 yards southeast of the mid-point of the SE edge of the experimental plots; vegetation of bunch grasses, cheat grass, and scattered brush; the soil was dry when described.

Profile:

Horizon, depth (inches)	Description (dry colors given first)
A 0-14	Pale brown (10YR 6/3) loamy fine sand, brown to dark brown (10YR 4/3) when moist; weak medium blocky structure; loose when dry or moist, non-plastic, non-sticky; many fine and medium roots; common fine and few medium tubular pores; pH 8.4 (TB); no effervescence; clear smooth lower boundary.
IIB1 14-20	Pale brown (10YR 6/3) silt loam, brown to dark brown (10YR 4/3) when moist; weak medium blocky structure; slightly hard when dry, loose when moist, non-plastic, non-sticky; many fine and medium roots; common fine and few medium tubular pores; pH 8.4 (TB); slight effervescence; clear smooth lower boundary.
IIB2ca 20-30	Very pale brown (10YR 7/3) silt loam, brown to dark brown (10YR 4/3) when moist; strong coarse subangular blocky structure; slightly hard when dry, loose when moist, slightly plastic, slightly sticky; many fine and medium roots; common fine and few medium tubular pores; pH 8.4 (TB); strong effervescence; clear irregular lower boundary.
IICca 30-40+	"Soft" caliche formed from material similar to that of the IIB2 horizon: very coarse subangular blocky structure, weakly cemented, with irregular veins of calcium carbonate.

The lower horizons (IIB and IIC) of this soil have developed in silt similar to that of the Sagemoor series, but are more strongly alkaline due to the greater accumulation of carbonates. The overlying A horizon is similar to that of the Sagehill series, and probably developed in fine sand which was deposited over the silt.

Classification: Xerollic Camborthid; coarse-silty, mixed, mesic.

I-2. Soil Textural Analysis
(O.S.U. Soil Physics Laboratory, Nov. 1973)

Horizon	Depth	% > 2 mm	Particle size distribution (% of < 2 mm)					
			Sand					
			very coarse	coarse	medium	fine	very fine	total sand
	inches		2-1	1-.5	.5-.25	.25-.1	.1-.05	2-.05
A	0-14	-	0.01	0.24	3.47	38.56	36.80	79.08
IIB2ca	14-30	-	0.21	0.39	1.33	9.98	14.06	25.97
IICca	30-40	-	0.09	0.28	0.27	1.22	11.24	13.10

Horizon	Depth	Silt			Clay	Textural class
		coarse	fine	total silt	total clay	
	inches	0.05-0.02	0.02-0.002	0.05-0.002	< 0.002	
A	0-14	15.13	2.23	17.36	3.56	loamy fine sand
IIB2ca	14-30	43.27	22.78	66.05	7.98	silt loam
IICca	30-40	58.25	22.56	80.81	6.09	silt loam to silt

I-3. Soil Chemical Analysis
(O.S.U. Soil Testing Laboratory, Oct. 1971)

soil depth	pH	CEC	Ca	Mg	K	Na	soluble salts
inches		---- me/100g ----					mmho/cm
0-6[1]	8.1	8.1	9.7	1.1	0.46	trace	0.20
6-12[1]	8.3	8.8	17.0	1.2	0.41	trace	0.20
12-24	8.4				0.34	0.10	0.28
24-36	8.5				0.14	0.14	0.27
36-48	8.6				0.14	0.10	0.25
48-60	8.6				0.14	0.14	0.25

soil depth	organic matter	total nitrogen	NO_3-N	P	SO_4-S	Zn	B
inches	%	%	---- ppm ----				
0-6[1]	0.47	0.03	2.38	5	0.9	0.21	0.26
6-12[1]	0.54	0.04	1.86	3	0.6	0.23	0.29
12-24			4.70	5	1.5		
24-36			0.78	2	2.2		
36-48			0.56	2	1.4		
48-60			2.0	2	0.9		

[1] Average of 10 samples.

APPENDIX II

Table II-1. Effect of waste treatments on alfalfa yield.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	1972 June 29	1972 Aug. 3	1972 Sept. 10	1973 May 31	1973 July 11	1973 Aug. 22
			ton/acre					
3C	0	80	0.77	3.12	1.91	1.33	1.95	1.18
6D	0	80	0.68	2.50	2.55	1.57	2.70	1.99
10A	0	80	0.32	1.16	1.37	0.93	2.40	2.10
3B	0	200	0.91	3.16	2.17	1.47	2.26	1.18
6E	0	200	1.54	1.83	1.91	1.20	1.92	1.35
10C	0	200	1.91	2.83	2.13	1.57	2.26	1.82
3A	0	400	1.07	2.83	nr[1]	1.29	2.16	1.42
6F	0	400	2.31	2.49	2.32	1.11	2.33	1.35
10B	0	400	2.31	2.29	2.06	1.47	2.67	2.24
2B	100	200	0.57	2.66	nr	1.27	2.09	1.01
8A	100	200	0.54	2.37	1.75	1.44	2.33	1.70
12E	100	200	1.00	2.62	2.36	1.07	2.23	1.70
2A	100	400	1.40	2.54	nr	0.97	1.23	1.18
8B	100	400	1.13	2.95	2.32	1.71	2.64	2.41
12D	100	400	1.09	2.91	2.25	1.11	2.67	2.10
2C	100	600	0.73	3.08	1.07	1.23	2.23	1.24
8C	100	600	1.91	2.91	3.09	1.36	2.26	1.79
12F	100	600	1.00	2.41	2.32	1.13	1.92	1.24
1E	200	200	1.00	2.00	2.10	1.21	1.88	0.84
8F	200	200	0.36	nr	1.91	1.20	1.16	0.89
11B	200	200	0.23	1.95	2.59	1.73	2.63	2.32
1F	200	400	0.64	2.45	2.13	1.07	1.61	0.95
8E	200	400	1.00	2.70	2.25	1.08	1.47	1.24
11A	200	400	0.95	2.37	1.83	1.81	2.53	2.10
1D	200	600	0.91	2.95	2.10	1.31	2.23	1.46
8D	200	600	0.64	2.20	2.02	1.07	1.64	1.01
11C	200	600	0.59	2.16	2.40	1.64	1.99	0.92
4D	400	200	0.25	2.58	2.21	1.01	1.99	1.59
6A	400	200	0	1.62	nr	1.19	1.44	1.70
9E	400	200	0.10	1.91	1.37	1.54	2.09	1.51
4F	400	400	0.14	2.32	2.59	1.00	1.64	1.46
6C	400	400	0	1.53	nr	0.98	1.64	1.29
9F	400	400	0	0.21	0.34	1.07	1.61	1.06
4E	400	600	0.27	2.73	2.63	1.06	1.85	1.59
6B	400	600	0	1.29	nr	0.92	1.64	1.42
9D	400	600	0	1.08	0.84	1.47	1.82	1.20

[1] Not recorded.

Table II-2. Effect of waste treatments on fescue yield.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	1972 June 29	1972 Aug. 3	1972 Sept. 10	1973 May 31	1973 July 11	1973 Aug. 22
			ton/acre					
4C	0	250	1.19	1.75	1.10	0	0.17	0.82
5D	0	250	0.45	1.79	1.10	0	0.17	0.76
9A	0	250	0.31	2.20	0.91	0	0.10	0.82
4B	0	500	1.31	2.30	1.98	0	0.10	0.64
5E	0	500	1.31	3.20	2.29	0	0.13	0.76
9C	0	500	1.86	2.55	2.36	0	0.36	1.18
4A	0	1000	1.17	2.82	1.94	0	0.56	1.31
5F	0	1000	1.38	3.10	3.04	0	0.83	1.18
9B	0	1000	1.59	2.99	2.48	0	0.40	1.37
1B	100	500	1.07	2.99	1.68	0	0.30	0.76
7A	100	500	0.69	3.27	1.30	0	0.26	0.64
11E	100	500	1.45	1.89	2.06	0	0.17	0.82
1A	100	1000	1.15	2.99	1.60	0	0.43	1.21
7B	100	1000	1.45	2.61	2.13	0	0.86	1.43
11D	100	1000	1.41	2.34	2.13	0	0.80	1.06
1C	100	2000	0.81	2.65	1.49	0	0.73	1.54
7C	100	2000	1.45	2.51	2.71	0	0.79	1.60
11F	100	2000	1.59	1.65	2.25	0	1.36	1.79
2E	200	500	0.66	3.68	2.36	0	0.23	0.45
7F	200	500	0.97	2.24	2.13	0	0.17	0.89
12B	200	500	0.59	3.17	2.29	0	0.10	1.98
2F	200	1000	0.55	3.37	2.81	0	0.80	1.66
7E	200	1000	0.83	2.75	2.40	0	0.76	1.24
12A	200	1000	1.14	3.20	1.52	0	0.66	1.91
2D	200	2000	0.72	2.78	2.29	0	0.83	1.31
7D	200	2000	0.69	2.27	2.44	0	1.06	0.89
12C	200	2000	0.66	2.51	1.91	0	0.93	1.91
3D	400	500	0.62	1.99	1.87	0	0.70	nr[1]
5A	400	500	0.14	3.30	1.33	0	0.33	0.16
10E	400	500	0.83	2.99	2.10	0	0.10	0.82
3F	400	1000	0.52	3.20	1.79	0	1.03	0.89
5C	400	1000	0.17	3.30	2.40	0	0.46	0.76
10F	400	1000	0.97	3.37	2.51	0	1.09	2.40
3E	400	2000	0.28	2.41	1.60	0	1.23	0.82
5B	400	2000	0.17	2.13	1.71	0	0.83	0.45
10D	400	2000	0.52	2.03	1.71	0	1.16	1.18

[1] Not recorded.

APPENDIX III

Table III-1. Major plant nutrient analyses of wheat harvested in April 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3-4C[1]	0	80	2.57	0.21	0.31	0.36	0.16	2.98
5-6D		80	2.76	0.23	0.33	0.36	0.12	3.22
9-10A		80	2.97	0.24	0.38	0.36	0.14	3.00
3-4B		130	2.74	0.23	0.35	0.34	0.13	3.22
5-6E		130	3.00	0.26	0.38	0.34	0.14	3.50
9-10C		130	2.94	0.22	0.32	0.32	0.11	3.22
3-4A		180	2.99	0.18	0.33	0.32	0.14	3.18
5-6F		180	3.49	0.23	0.39	0.36	0.15	3.55
9-10B		180	3.19	0.24	0.37	0.35	0.15	3.38
1-2B	100	130	2.61	0.27	0.30	0.35	0.11	3.05
7-8A		130	2.24	0.25	0.33	0.38	0.10	2.82
11-12E		130	1.87	0.31	0.32	0.34	0.12	3.00
1-2A		180	2.76	0.21	0.37	0.32	0.11	2.92
7-8B		180	2.51	0.25	0.32	0.36	0.11	3.02
11-12D		180	3.08	0.28	0.38	0.34	0 12	3.15
1-2C		280	3.44	0.30	0.37	0.38	0.14	3.45
7-8C		280	3.07	0.25	0.34	0.36	0.13	3.55
11-12F		280	3.85	0.33	0.40	0.36	0.12	3.65
1-2E	200	130	2.47	0.30	0.31	0.38	0.13	2.82
7-8F		130	2.27	0.31	0.29	0.38	0.13	2.65
11-12B		130	2.94	0.32	0.31	0.37	0.14	3.02
1-2F		180	3.11	0.37	0.38	0.42	0.14	3.48
7-8E		180	2.62	0.29	0.32	0.36	0.12	2.82
11-12A		180	2.91	0.29	0.27	0.41	0.15	2.90
1-2D		280	3.04	0.32	0.42	0.38	0.13	3.08
7-8D		280	2.90	0.28	0.34	0.34	0.11	3.10
11-12C		280	3.62	0.33	0.34	0.38	0.12	3.14
3-4D	400	130	4.31	0.54	0.48	0.42	0.16	4.45
5-6A		130	2.76	0.53	0.31	0.50	0.14	2.95
9-10E[2]		130	3.93	0.53	0.39	0.33	0.15	3.28
3-4F		180	5.02	0.59	0.48	0.32	0.16	3.62
5-6C		180	2.16	0.33	0.26	0.42	0.13	2.35
9-10F[2]		180	3.54	0.32	0.37	0.32	0.14	3.28
3-4E		280	4.28	0.53	0.49	0.40	0.18	4.05
5-6B		280	3.02	0.38	0.33	0.42	0.14	2.95
9-10D[2]		280	4.49	0.47	0.52	0.32	0.16	3.25

[1] Sample collected from several locations within plots 3C and 4C.

[2] No sewage added.

Table III-2. Major plant nutrient analyses of wheat harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3C	0	80	2.53	0.40	0.25	0.28	0.12	2.88
6D		80	ns[1]					
10A		80	ns					
3B		200	2.64	0.36	0.23	0.19	0.11	2.62
6E		200	ns					
10C		200	ns					
3A		400	2.72	0.45	0.23	0.20	0.11	3.30
6F		400	ns					
10B		400	ns					
2B	100	200	2.23	0.51	0.22	0.18	0.10	2.85
8A		200	ns					
12E		200	ns					
2A		400	2.40	0.49	0.24	0.20	0.10	3.30
8B		400	ns					
12D		400	ns					
2C		600	2.20	0.48	0.24	0.23	0.10	2.80
8C		600	ns					
12F		600	ns					
1E	200	200	2.44	0.54	0.33	0.24	0.10	3.15
8F		200	ns					
11B		200	ns					
1F		400	2.37	0.51	0.24	0.20	0.10	3.15
8E		400	ns					
11A		400	ns					
1D		600	2.77	0.41	0.32	0.24	0.10	2.95
8D		600	ns					
11C		600	ns					

[1] No sample collected.

Table III-3. Major plant nutrient analyses of fescue harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
4C	0	200	1.94	0.40	0.23	0.24	0.15	3.45
5D		200	2.16	0.32	0.18	0.26	0.16	3.28
9A		200	2.00	0.35	0.19	0.29	0.18	3.18
4B		400	3.37	0.47	0.22	0.23	0.17	3.66
5E		400	3.41	0.41	0.30	0.35	0.23	4.14
9C		400	3.10	0.47	0.30	0.24	0.18	3.54
4A		600	3.19	0.49	0.32	0.28	0.20	4.23
5F		600	3.72	0.44	0.33	0.32	0.22	4.20
9B		600	3.69	0.43	0.37	0.27	0.19	3.63
1B	100	400	2.97	0.46	0.35	0.29	0.20	4.29
7A		400	3.54	0.43	0.47	0.45	0.24	4.26
11E		400	3.15	0.42	0.32	0.31	0.20	3.99
1A		600	3.44	0.49	0.36	0.36	0.25	3.98
7B		600	4.12	0.42	0.43	0.34	0.21	4.17
11D		600	3.79	0.43	0.37	0.29	0.22	4.05
1C		1200	4.10	0.51	0.55	0.48	0.21	4.44
7C		1200	4.38	0.52	0.37	0.26	0.18	3.90
11F		1200	4.26	0.40	0.50	0.32	0.18	3.75
2E	200	400	3.36	0.40	0.32	0.48	0.21	3.99
7F		400	2.90	0.44	0.55	0.30	0.17	3.69
12B		400	3.07	0.42	0.40	0.33	0.18	3.63
2F		600	3.48	0.42	0.30	0.40	0.20	3.70
7E		600	3.08	0.41	0.47	0.32	0.20	3.92
12A		600	3.69	0.47	0.49	0.28	0.18	3.62
2D		1200	4.39	0.43	0.37	0.38	0.20	3.99
7D		1200	4.05	0.43	0.50	0.33	0.18	3.78
12C		1200	4.38	0.41	0.64	0.32	0.17	3.58
3D	400	400	3.28	0.39	0.55	0.32	0.20	4.08
5A		400	2.96	0.46	0.35	0.30	0.18	3.72
10E[1]		400	3.34	0.38	0.32	0.28	0.20	3.69
3F		600	3.78	0.48	0.72	0.31	0.22	3.38
5C		600	3.73	0.40	0.58	0.28	0.18	3.42
10F[1]		600	3.81	0.36	0.48	0.26	0.19	3.55
3E		1200	4.34	0.44	0.78	0.28	0.20	3.82
5B		1200	4.37	0.46	0.62	0.24	0.18	3.78
10D[1]		1200	4.16	0.40	0.85	0.30	0.20	3.84

[1] No sewage added.

Table III-4. Major plant nutrient analyses of fescue harvested in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			----------	----------	---------- %	----------	----------	----------
4C	0	250	na[1]	0.14	0.29	0.28	0.22	2.97
5D		250	1.48	0.12	0.24	0.28	0.18	2.46
9A		250	na	0.12	0.23	0.36	0.24	2.52
4B		500	2.42	0.16	0.34	0.28	0.27	3.09
5E		500	na	0.15	0.32	0.30	0.26	3.30
9C		500	na	0.15	0.16	0.26	0.24	2.70
4A		1000	na	0.16	0.20	0.28	0.26	3.21
5F		1000	na	0.18	0.37	0.31	0.23	3.18
9B		1000	2.52	0.18	0.20	0.29	0.29	3.15
1B	100	500	2.83	0.20	0.34	0.28	0.26	3.12
7A		500	na	0.20	0.42	0.26	0.28	3.00
11E		500	na	0.19	0.36	0.31	0.24	3.03
1A		1000	na	0.19	0.37	0.26	0.24	2.91
7B		1000	na	0.22	0.37	0.24	0.26	2.88
11D		1000	2.29	0.16	0.29	0.30	0.25	2.85
1C		2000	na	0.25	0.47	0.34	0.24	2.82
7C		2000	3.63	0.24	0.37	0.26	0.21	3.05
11F		2000	na	0.23	0.37	0.26	0.16	3.18
2E	200	500	2.38	0.18	0.27	0.32	0.19	2.91
7F		500	na	0.19	0.32	0.31	0.25	2.43
12B		500	na	0.18	0.29	0.28	0.18	2.91
2F		1000	na	0.18	0.34	0.32	0.24	3.09
7E		1000	2.61	0.19	0.34	0.29	0.23	2.73
12A		1000	na	0.20	0.34	0.29	0.22	3.18
2D		2000	na	0.23	0.37	0.32	0.21	3.42
7D		2000	na	0.22	0.42	0.32	0.22	2.67
12C		2000	3.62	0.24	0.28	0.22	0.19	3.39
3D	400	500	na	0.17	0.24	0.30	0.17	2.55
5A		500	2.22	0.18	0.37	0.25	0.18	2.91
10E[2]		500	na	0.18	0.34	0.28	0.26	3.06
3F		1000	3.91	0.25	0.49	0.31	0.24	2.76
5C		1000	na	0.18	0.37	0.27	0.20	3.54
10F[2]		1000	na	0.19	0.34	0.27	0.23	2.88
3E		2000	na	0.27	0.60	0.30	0.20	3.27
5B		2000	na	0.27	0.49	0.34	0.18	3.96
10D[2]		2000	3.43	0.21	0.54	0.26	0.22	3.21

[1] No analysis.

[2] No sewage added.

Table III-5. Major plant nutrient analyses of fescue harvested in July 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
4C	0	100	ns[1]	ns	ns	ns	ns	ns
5D		100	2.33	0.29	0.30	0.39	0.22	3.33
9A		100	na[2]	0.27	0.28	0.40	0.22	3.03
4B		200	2.10	0.28	0.28	0.21	0.20	2.43
5E		200	na	0.24	0.32	0.32	0.24	3.90
9C		200	na	0.25	0.26	0.32	0.23	4.02
4A		400	na	0.25	0.30	0.20	0.20	2.70
5F		400	na	0.29	0.27	0.32	0.24	4.20
9B		400	3.04	0.28	0.28	0.26	0.20	3.24
1B	100	100	2.72	0.33	0.30	0.44	0.28	4.05
7A		100	na	0.29	0.32	0.44	0.24	4.02
11E		100	na	0.27	0.26	0.32	0.20	3.00
1A		200	na	0.35	0.28	0.44	0.26	3.90
7B		200	na	0.28	0.30	0.32	0.23	4.23
11D		200	3.14	0.29	0.26	0.31	0.22	3.72
1C		400	na	0.33	0.35	0.38	0.26	3.93
7C		400	3.28	0.31	0.28	0.23	0.18	3.75
11F		400	na	0.36	0.27	0.28	0.18	3.00
2E	200	100	2.71	0.32	0.32	0.50	0.24	3.69
7F		100	na	0.28	0.26	0.44	0.18	3.09
12B		100	na	0.29	0.23	0.36	0.20	3.21
2F		200	na	0.29	0.30	0.30	0.22	3.81
7E		200	3.16	0.28	0.30	0.38	0.19	3.65
12A		200	na	0.29	0.26	0.35	0.20	3.93
2D		400	na	0.33	0.50	0.32	0.22	3.90
7D		400	na	0.28	0.31	0.37	0.20	3.63
12C		400	3.27	0.33	0.30	0.34	0.24	3.69
3D	400	100	na	0.33	0.26	0.33	0.22	3.21
5A		100	2.24	0.38	0.24	0.35	0.22	3.81
10E[3]		100	na	0.28	0.24	0.26	0.16	3.30
3F		200	2.90	0.39	0.34	0.28	0.24	3.39
5C		200	na	0.28	0.32	0.22	0.20	4.14
10F[3]		200	na	0.29	0.33	0.38	0.26	3.81
3E		400	na	0.41	0.36	0.28	0.20	3.39
5B		400	na	0.33	0.32	0.23	0.18	4.02
10D[3]		400	3.00	0.31	0.32	0.22	0.17	3.75

[1] No sample collected.

[2] No analysis.

[3] No sewage added.

Table III-6. Major plant nutrient analyses of alfalfa harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3C	0	80	3.56	0.33	0.50	1.60	0.26	2.85
6D		80	3.91	0.30	0.40	1.36	0.20	2.58
10A		80	3.55	0.37	0.22	1.54	0.24	2.70
3B		200	4.15	0.39	0.42	1.69	0.30	3.24
6E		200	3.17	0.33	0.29	1.55	0.22	2.91
10C		200	3.58	0.36	0.25	1.74	0.25	3.00
3A		400	3.20	0.39	0.27	1.41	0.23	3.03
6F		400	3.69	0.39	0.33	1.46	0.23	3.18
10B		400	3.04	0.33	0.25	1.48	0.22	2.79
2B	100	200	3.11	0.38	0.43	1.70	0.24	3.33
8A		200	3.10	0.32	0.34	1.39	0.20	3.09
12E		200	3.35	0.28	0.35	1.45	0.20	2.91
2A		400	2.95	0.40	0.43	1.63	0.24	3.40
8B		400	3.11	0.28	0.41	1.40	0.20	2.48
12D		400	2.76	0.28	0.44	1.34	0.20	2.32
2C		600	3.70	0.37	0.40	1.61	0.23	3.21
8C		600	3.05	0.38	0.39	1.46	0.21	2.82
12F		600	3.24	0.34	0.53	1.53	0.22	3.00
1E	200	200	3.47	0.40	0.47	1.78	0.21	3.30
8F		200	3.10	0.35	0.37	1.61	0.18	2.97
11B		200	3.10	0.34	0.43	1.62	0.23	2.91
1F		400	3.59	0.33	0.42	1.56	0.18	2.50
8E		400	3.12	0.31	0.46	1.45	0.18	2.60
11A		400	3.00	0.37	0.49	1.62	0.22	2.88
1D		600	3.60	0.34	0.44	1.60	0.21	3.06
8D		600	3.07	0.31	0.56	1.53	0.19	2.64
11C		600	3.04	0.32	0.40	1.43	0.22	2.91
4D	400	200	3.88	0.37	0.46	1.82	0.20	3.21
6A		200	3.37	0.34	0.46	1.75	0.28	2.97
9E[1]		200	3.52	0.39	0.79	2.05	0.34	2.97
4F		400	3.07	0.38	0.59	1.69	0.21	2.90
6C		400	3.50	0.31	0.61	2.01	0.28	2.65
9F[1]		400	3.61	0.31	0.32	1.30	0.23	2.15
4E		600	3.54	0.38	0.58	1.93	0.24	3.24
6B		600	3.64	0.37	0.72	2.13	0.29	3.03
9D[1]		600	3.35	0.35	0.80	2.10	0.30	2.82

[1] No sewage added.

Table III-7. Major plant nutrient analyses of alfalfa harvested in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3C	0	80	na[1]	0.25	0.27	0.65	0.20	2.16
6D		80	2.74	0.28	0.24	0.70	0.18	2.61
10A		80	na	0.25	0.28	0.66	0.19	2.31
3B		200	2.99	0.25	0.26	0.78	0.22	2.16
6E		200	na	0.23	0.22	0.54	0.14	2.19
10C		200	na	0.26	0.28	0.72	0.19	2.07
3A		400	na	0.31	0.32	0.68	0.20	2.43
6F		400	na	0.31	0.24	0.59	0.18	2.40
10B		400	3.19	0.27	0.32	0.66	0.20	2.58
2B	100	200	2.46	0.31	0.29	0.70	0.17	2.55
8A		200	na	0.28	0.24	0.66	0.15	2.64
12E		200	na	0.33	0.28	0.68	0.16	2.43
2A		400	na	0.36	0.28	0.66	0.16	2.64
8B		400	na	0.25	0.28	0.66	0.15	2.49
12D		400	3.00	0.29	0.32	0.64	0.16	2.58
2C		600	na	0.19	0.26	0.70	0.23	2.34
8C		600	2.72	0.25	0.29	0.74	0.18	2.31
12F		600	na	0.35	0.38	0.72	0.17	2.52
1E	200	200	3.02	0.24	0.24	0.68	0.16	2.64
8F		200	na	0.46	0.28	0.57	0.15	2.25
11B		200	na	0.32	0.39	0.70	0.18	2.34
1F		400	na	0.27	0.30	0.66	0.16	2.76
8E		400	3.17	0.31	0.27	0.62	0.13	2.43
11A		400	na	0.33	0.29	0.62	0.18	2.46
1D		600	na	0.18	0.28	0.69	0.16	2.22
8D		600	na	0.35	0.39	0.70	0.18	2.49
11C		600	3.15	0.28	0.32	0.68	0.18	2.49
4D	400	200	na	0.28	0.26	0.62	0.14	2.61
6A		200	3.49	0.37	0.30	0.62	0.15	2.73
9E[2]		200	na	0.29	0.30	0.60	0.18	2.25
4F		400	3.23	0.29	0.26	0.67	0.19	2.73
6C		400	ns[3]	ns	ns	ns	ns	ns
9F[2]		400	na	0.28	0.34	0.64	0.18	1.95
4E		600	3.16	0.24	0.30	0.64	0.16	2.70
6B		600	3.06	0.32	0.34	0.66	0.18	2.76
9D[2]		600	4.54	0.36	0.44	0.80	0.22	2.16

[1] No analysis.

[2] No sewage added.

[3] No sample collected.

Table III-8. Major plant nutrient analyses of alfalfa harvested in May 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3C	0	0	na[1]	0.21	0.21	1.35	0.17	2.38
6D			3.20	0.21	0.32	1.4	0.16	2.94
10A			na	0.22	0.23	1.35	0.18	2.64
3B			3.01	0.22	0.29	1.3	0.16	2.36
6E			na	0.16	0.17	1.05	0.10	1.80
10C			na	0.21	0.33	1.45	0.15	2.50
3A			na	0.21	0.24	1.3	0.16	2.40
6F			na	0.22	0.38	1.3	0.16	2.56
10B			2.73	0.22	0.33	1.2	0.15	2.54
2B	100	0	2.67	0.23	0.33	1.25	0.14	2.60
8A			na	0.25	0.45	1.1	0.13	2.62
12E			na	0.17	0.37	1.6	0.14	2.28
2A			na	0.21	0.23	0.95	0.10	2.72
8B			na	0.19	0.36	1.35	0.24	2.60
12D			3.00	na	0.18	1.25	0.12	2.64
2C			na	0.22	0.35	1.4	0.15	2.58
8C			3.00	0.22	0.29	1.25	0.12	2.68
12F			na	0.21	0.23	1.35	0.14	2.44
1E	200	0	2.94	0.21	0.38	1.35	0.14	2.46
8F			na	0.13	0.40	1.55	0.18	2.08
11B			na	0.29	0.55	1.4	0.16	2.54
1F			na	0.18	0.33	0.95	0.10	2.62
8E			2.48	0.18	0.33	1.3	0.12	2.26
11A			na	0.20	0.40	1.15	0.13	2.48
1D			na	0.18	0.37	1.15	0.12	2.26
8D			na	0.16	0.35	1.3	0.14	2.38
11C			2.34	0.18	0.19	0.8	0.08	2.50
4D	400	0	na	0.19	0.34	1.45	0.14	2.32
6A			2.40	0.12	0.37	1.35	0.14	2.24
9E[2]			na	0.18	0.32	1.25	0.15	2.44
4F			2.85	0.14	0.35	1.6	0.14	2.22
6C			na	0.18	0.31	1.6	0.14	2.54
9F[2]			na	0.19	0.40	1.58	0.19	2.33
4E			na	0.21	0.26	1.05	0.12	2.52
6B			na	0.19	0.26	1.55	0.12	2.68
9D[2]			3.03	0.16	0.55	1.52	0.17	2.24

[1] No analysis.

[2] No sewage added.

Table III-9. Major plant nutrient analyses of alfalfa harvested in August 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	N	P	S	Ca	Mg	K
			%					
3C	0	0	na[1]	0.24	0.27	1.35	0.22	2.52
6D			2.42	0.28	0.28	1.55	0.22	2.32
10A			na	0.31	0.33	1.6	0.21	2.54
3B			2.21	0.28	0.37	1.40	0.30	2.46
6E			na	0.30	0.22	1.35	0.20	2.30
10C			na	0.31	0.65	1.35	0.24	2.48
3A			na	0.28	0.56	1.50	0.25	2.62
6F			na	0.29	0.33	1.35	0.24	2.58
10B			3.19	0.31	0.49	1.7	0.24	2.66
2B	100	0	2.44	0.33	0.32	1.40	0.22	2.74
8A			na	0.28	0.23	1.50	0.20	2.68
12E			na	0.31	0.33	1.2	0.18	2.64
2A			na	0.28	0.38	1.30	0.20	2.48
8B			na	0.40	0.24	1.30	0.13	2.76
12D			2.89	0.31	0.36	1.3	0.20	2.60
2C			na	0.33	0.40	1.45	0.23	2.52
8C			3.19	0.30	0.30	1.4	0.22	2.56
12F			na	0.36	0.56	1.25	0.22	2.58
1E	200	0	2.68	0.33	0.52	1.40	0.28	2.42
8F			na	0.29	0.40	1.25	0.22	2.84
11B			na	0.30	0.44	1.35	0.17	2.58
1F			na	0.31	0.40	1.45	0.22	2.58
8E			2.65	0.30	0.48	1.3	0.22	2.32
11A			na	0.30	0.36	1.25	0.18	2.50
1D			na	0.35	0.45	1.30	0.24	2.80
8D			na	0.31	0.49	1.15	0.22	2.80
11C			2.71	0.35	0.56	1.3	0.28	2.18
4D	400	0	na	0.31	0.37	1.25	0.24	2.64
6A			2.73	0.28	0.44	1.60	0.26	2.50
9E[2]			na	0.27	0.35	1.2	0.18	2.70
4F			2.68	0.35	0.69	1.45	0.26	2.78
6C			na	0.28	0.48	1.45	0.20	2.52
9F[2]			na	0.22	0.37	1.1	0.18	2.50
4E			na	0.27	0.16	1.35	0.18	2.68
6B			na	0.23	0.40	1.45	0.24	2.62
9D[2]			2.42	0.25	0.46	1.4	0.21	2.92

[1] No analysis.

[2] No sewage added.

APPENDIX IV

Table IV-1. Micronutrient analyses of wheat harvested in April 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B	Mo	Co
				ppm						
3-4C[1]	0	80	0.048	2440	103	3	43	5.1	0.5	0.84
5-6D		80	0.050	785	68	3	44	3.9	0.5	0.42
9-10A		80	0.053	1185	68	9	25	4.4	0.8	0.48
3-4B		130	0.045	940	68	2	28	4.5	0.8	0.36
5-6E		130	0.047	1150	75	2	24	4.2	0.5	0.75
9-10C		130	0.047	505	70	10	23	5.0	0.3	0.38
3-4A		180	0.050	1545	79	5	23	6.7	0.5	0.42
5-6F		180	0.060	1270	86	12	28	5.2	0.4	0.68
9-10B		180	0.054	1600	93	10	31	7.0	0.5	0.71
1-2B	100	130	0.059	615	70	6	43	17	1.0	0.40
7-8A		130	0.044	800	61	20	45	17	1.1	0.31
11-12E		130	0.056	985	70	1	48	26	1.3	0.41
1-2A		180	0.087	835	72	8	78	15	1.0	0.32
7-8B		180	0.049	605	61	1	53	17	0.7	0.41
11-12D		180	0.058	1105	68	4	64	29	0.5	0.48
1-2C		280	0.059	1340	77	9	65	18	0.7	0.44
7-8C		280	0.048	1340	68	5	66	19	0.8	0.55
11-12F		280	0.051	795	60	5	77	40	0.9	0.55
1-2E	200	130	0.054	1155	101	13	66	17	1.1	0.69
7-8F		130	0.051	1445	81	11	51	18	1.3	0.61
11-12B		130	0.063	1690	93	10	86	105	1.3	0.38
1-2F		180	0.063	1530	102	11	69	17	0.9	0.44
7-8E		180	0.050	1745	84	1	66	35	0.9	0.51
11-12A		180	0.057	2540	92	11	82	140	1.0	0.63
1-2D		280	0.057	1560	109	10	87	22	0.8	0.54
7-8D		280	0.052	1030	74	14	72	40	1.0	0.44
11-12C		280	0.063	1315	100	14	100	135	1.2	0.34
3-4D	400	130	0.094	615	74	9	220	113	1.7	0.62
5-6A		130	0.104	890	69	1	92	56	1.0	0.36
9-10E[2]		130	0.095	895	94	9	353	41	1.4	0.83
3-4F		180	0.085	890	103	8	271	100	1.5	0.58
5-6C		180	0.081	1575	184	8	134	83	1.2	0.48
9-10F[2]		180	0.067	910	100	9	343	102	1.2	0.68
3-4E		280	0.090	1465	103	14	199	106	2.4	0.51
5-6B		280	0.081	1635	147	10	175	114	1.2	0.31
9-10D[2]		280	0.084	835	118	16	436	93	1.7	0.75

[1] Sample collected from several locations within plots 3C and 4C.

[2] No sewage added.

Table IV-2. Micronutrient analyses of wheat harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B	Mo	Co
				ppm						
3C	0	80	0.20	294	72	na[1]	38	4.2	0.2	0.31
6D		80	ns[2]							
10A		80	ns							
3B		200	0.16	144	72	na	29	2.6	0.7	0.40
6E		200	ns							
10C		200	ns							
3A		400	0.18	148	71	na	32	3.2	0.4	0.32
6F		400	ns							
10B		400	ns							
2B	100	200	0.21	156	54	na	68	2.7	1.8	0.36
8A		200	ns							
12E		200	ns							
2A		400	0.20	263	63	na	66	3.9	1.4	0.32
8B		400	ns							
12D		400	ns							
2C		600	0.24	139	61	na	53	2.9	0.7	0.40
8C		600	ns							
12F		600	ns							
1E	200	200	0.25	274	40	na	91	3.9	0.8	0.47
8F		200	ns							
11B		200	ns							
1F		400	0.29	268	77	na	73	2.6	1.2	0.51
8E		400	ns							
11A		400	ns							
1D		600	0.31	275	68	na	107	6.1	0.8	0.43
8D		600	ns							
11C		600	ns							

[1] No analysis.

[2] No sample collected.

Table IV-3. Micronutrient analyses of fescue harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na	Fe	Mn	Cu	Zn	B	Mo	Co	Cr
			%	ppm							
4C	0	200	0.54	86	70	11.	52	3.8	1.1	0.53	0.31
5D		200	0.36	122	52	9	12	2.5	1.6	0.32	0.56
9A		200	0.34	134	53	14	24	4.0	0.7	0.28	0.42
4B		400	0.27	138	142	10	34	3.0	0.4	0.61	0.52
5E		400	0.38	156	111	10	40	4.6	0.5	0.55	0.96
9C		400	0.43	178	167	7	43	3.1	2.2	0.71	0.98
4A		600	0.28	168	120	18	62	2.3	0.4	0.71	0.93
5F		600	0.37	143	127	9	31	5.7	0.5	0.61	0.56
9B		600	0.56	130	185	13	39	4.5	0.4	0.81	0.32
1B	100	400	0.46	192	115	14	111	5.7	1.0	0.51	0.88
7A		400	0.43	218	136	23	87	25	1.9	0.71	0.74
11E		400	0.51	135	103	14	80	15	1.7	0.36	0.48
1A		600	0.54	230	171	16	110	11	0.5	0.68	0.80
7B		600	0.48	140	162	16	99	17	1.2	0.48	0.74
11D		600	0.50	146	123	10	67	13	1.3	0.47	0.85
1C		1200	0.57	230	174	15	220	12	0.4	0.82	1.09
7C		1200	0.46	156	210	12	89	6.5	1.0	0.78	0.47
11F		1200	0.56	180	198	16	74	8.1	1.0	0.94	0.58
2E	200	400	0.45	193	89	12	190	18	0.6	0.82	0.40
7F		400	0.50	163	122	15	82	4.7	1.3	0.55	0.68
12B		400	0.50	132	111	20	74	11	2.2	0.70	0.48
2F		600	0.49	210	164	17	164	16	0.5	0.50	0.98
7E		600	0.38	142	127	14	62	10.5	1.0	0.61	0.94
12A		600	0.40	146	113	15	80	11	1.6	0.67	0.58
2D		1200	0.59	224	245	9	124	18	0.2	0.75	0.58
7D		1200	0.42	128	197	12	95	14	0.8	0.72	0.64
12C		1200	0.76	172	239	21	149	15	1.3	0.90	0.23
3D	400	400	0.70	184	175	14	101	41	1.0	0.58	0.44
5A		400	0.45	149	92	17	72	15	1.5	0.65	0.48
10E[1]		400	0.56	182	90	13	124	10.5	1.1	0.41	0.48
3F		600	0.69	156	300	18	230	25	1.5	0.61	0.67
5C		600	0.59	210	207	18	117	16	3.0	0.49	0.44
10F[1]		600	0.64	229	157	20	285	12	1.7	0.49	0.74
3E		1200	0.65	184	328	18	221	85	1.9	0.65	0.33
5B		1200	0.56	164	232	23	158	9.6	1.0	1.14	0.40
10D[1]		1200	0.59	192	196	33	425	17	1.1	0.58	0.94

[1] No sewage added.

Table IV-4. Micronutrient analyses of fescue harvested in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B
				ppm				
4C	0	250	0.37	160	57	10	13	2.3
5D		250	0.39	170	66	20	38	1.6
9A		250	0.39	210	65	9	25	2.6
4B		500	0.58	280	139	9	15	2.6
5E		500	0.54	290	108	10	19	2.7
9C		500	0.49	400	116	10	94	2.4
4A		1000	0.57	270	134	11	16	2.0
5F		1000	0.61	300	175	13	69	3.3
9B		1000	0.79	260	173	na[1]	25	3.2
1B	100	500	0.70	280	122	16	60	3.4
7A		500	0.58	170	118	12	43	4.6
11E		500	0.46	180	116	9	35	2.5
1A		1000	0.65	360	159	11	44	2.8
7B		1000	0.70	240	197	13	50	3.0
11D		1000	0.49	460	142	na	20	3.2
1C		2000	0.55	180	275	16	110	3.2
7C		2000	1.02	260	280	18	58	2.7
11F		2000	0.84	270	270	14	61	1.9
2E	200	500	0.44	160	66	10	40	3.2
7F		500	0.46	420	86	10	43	3.9
12B		500	0.59	360	109	8	53	2.5
2F		1000	0.55	230	103	10	48	3.6
7E		1000	0.48	360	144	11	67	3.2
12A		1000	0.53	220	119	9	63	2.1
2D		2000	0.66	280	271	14	100	3.1
7D		2000	0.50	290	304	15	105	3.5
12C		2000	0.63	210	310	13	93	2.4
3D	400	500	0.80	290	138	10	50	5.1
5A		500	0.61	200	60	na	205	2.4
10E[2]		500	0.78	210	112	10	47	4.2
3F		1000	0.76	380	330	15	275	10.1
5C		1000	0.83	280	125	10	30	2.5
10F[2]		1000	0.77	290	180	9	130	3.9
3E		2000	0.73	220	435	18	325	7.4
5B		2000	0.67	230	281	17	100	3.0
10D[2]		2000	0.55	140	287	19	43	3.2

[1] No analysis.

[2] No sewage added.

Table IV-5. Micronutrient analyses of fescue harvested in July 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B	Mo	Co
				ppm						
4C	0	100	ns[1]	ns	ns	ns	ns	ns	ns	ns
5D		100	0.46	480	78	10	38	5.7	1.3	0.50
9A		100	0.65	460	78	6	37	6.7	1.5	0.34
4B		200	0.59	230	85	5	17	4.2	1.6	0.40
5E		200	0.67	360	214	11	39	8.9	0.6	0.74
9C		200	0.74	240	224	8	64	7.2	1.2	0.57
4A		400	0.68	250	117	9	20	3.9	1.0	0.60
5F		400	0.77	280	230	10	45	5.4	0.4	0.91
9B		400	0.70	140	199	8	36	3.8	0.8	0.50
1B	100	100	0.73	340	90	10	110	10.2	3.9	0.40
7A		100	0.60	340	93	7	56	11.4	1.6	0.30
11E		100	0.76	160	94	8	41	9.9	1.6	0.47
1A		200	0.60	170	127	10	80	9.3	3.1	0.57
7B		200	0.67	300	236	9	77	9.5	1.1	0.77
11D		200	0.65	180	252	11	64	11.0	1.0	0.81
1C		400	0.97	220	395	11	120	14.9	1.0	1.12
7C		400	1.01	245	326	13	64	5.3	0.2	0.84
11F		400	1.10	220	330	12	47	5.3	0.4	0.94
2E	200	100	0.64	210	95	9	125	10.7	2.4	0.54
7F		100	0.55	350	74	14	74	6.8	1.0	0.33
12B		100	0.67	160	92	7	56	5.9	1.6	0.50
2F		200	0.77	170	198	10	120	5.5	0.9	0.71
7E		200	0.58	200	176	13	68	8.7	0.6	0.57
12A		200	0.74	140	97	9	68	5.6	1.2	0.47
2D		400	0.94	240	330	12	93	7.2	0.6	0.94
7D		400	0.93	260	300	9	77	8.5	0.4	0.84
12C		400	0.81	200	360	10	100	11.0	0.5	0.96
3D	400	100	0.64	160	100	10	84	9.7	2.6	0.47
5A[2]		100	0.54	230	64	10	90	7.6	2.8	0.54
10E[2]		100	0.57	130	74	8	50	7.8	1.5	0.43
3F		200	0.73	170	295	24	310	7.1	2.8	0.74
5C		200	0.69	230	310	14	160	6.3	1.0	0.88
10F[2]		200	0.79	200	405	15	na[3]	10.3	2.4	0.71
3E		400	1.16	340	335	15	385	12.6	0.9	1.08
5B		400	0.87	240	320	12	185	6.1	1.2	0.94
10D[2]		400	0.91	250	325	10	215	8.5	0.8	0.96

[1] No sample collected.

[2] No sewage added.

[3] No analysis.

Table IV-6. Micronutrient analyses of alfalfa harvested in June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe ppm	Mn ppm	Cu ppm	Zn ppm	B ppm	Mo ppm	Co ppm	Cr ppm
3C	0	80	0.43	172	53	13	33	40	0.8	0.65	0.44
6D		80	0.39	158	124	16	91	35	1.9	0.76	0.47
10A		80	0.40	406	47	27	30	29	3.2	0.53	1.50
3B		200	0.41	257	88	11	38	34	1.3	0.70	0.40
6E		200	0.44	144	63	8	59	35	1.0	0.59	0.85
10C		200	0.39	204	62	15	35	32	2.8	0.77	0.48
3A		400	0.51	312	163	16	72	36	1.1	0.78	0.85
6F		400	0.49	174	120	10	43	43	0.6	0.61	0.38
10B		400	0.36	146	59	20	26	38	1.9	0.57	0.39
2B	100	200	0.57	479	79	16	67	46	3.1	0.79	0.88
8A		200	0.39	260	57	28	60	34	3.9	0.70	0.52
12E		200	0.44	168	78	6	77	50	3.8	0.51	0.34
2A		400	0.58	301	106	23	55	45	1.3	0.71	0.72
8B		400	0.43	166	122	33	90	41	1.3	0.83	0.90
12D		400	0.48	184	121	17	93	46	3.1	0.73	0.57
2C		600	0.42	360	97	12	48	41	3.1	0.60	0.76
8C		600	0.46	155	159	15	65	46	2.1	0.63	0.44
12F		600	0.54	190	122	13	80	45	2.0	0.62	0.48
1E	200	200	0.37	454	72	10	73	46	4.3	0.94	0.84
8F		200	0.44	308	77	22	47	39	4.4	0.57	0.81
11B		200	0.34	250	92	15	89	46	9.9	0.63	0.60
1F		400	0.39	242	74	11	80	47	3.6	0.84	0.60
8E		400	0.44	182	134	13	105	45	5.8	0.80	0.36
11A		400	0.33	170	147	17	118	53	5.5	0.73	0.60
1D		600	0.44	246	235	8	149	42	2.9	0.68	0.60
8D		600	0.44	267	211	8	99	52	6.7	0.80	0.58
11C		600	0.38	149	176	14	124	53	4.8	0.55	0.73
4D	400	200	0.36	280	85	5	69	39	7.0	0.94	0.59
6A		200	0.46	437	93	16	113	63	9.5	0.78	1.14
9E[1]		200	0.36	193	180	17	540	55	23.7	0.84	0.52
4F		400	0.44	432	136	14	104	53	6.0	0.86	1.20
6C		400	0.41	350	126	34	190	55	18.1	1.03	1.90
9F[1]		400	0.67	576	167	15	365	54	8.3	0.78	1.14
4E		600	0.33	322	110	23	74	59	3.7	0.90	0.67
6B		600	0.37	286	148	20	260	56	14.5	0.99	1.08
9D[1]		600	0.42	360	293	15	625	64	13.4	0.90	1.02

[1] No sewage added.

Table IV-7. Micronutrient analyses of alfalfa harvested in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B
				ppm				
3C	0	80	0.74	240	36	9	22	42
6D		80	0.61	240	48	12	19	35
10A		80	0.67	240	30	10	23	43
3B		200	0.78	290	19	12	22	32
6E		200	0.72	160	32	8	16	33
10C		200	0.78	270	32	11	23	46
3A		400	0.74	390	na[1]	13	20	39
6F		400	0.58	240	na	10	22	31
10B		400	0.74	240	47	10	18	42
2B	100	200	0.62	240	47	10	33	40
8A		200	0.74	260	39	10	32	45
12E		200	0.59	160	40	8	28	36
2A		400	0.78	460	64	9	28	35
8B		400	0.66	270	52	11	34	49
12D		400	0.58	160	62	8	37	38
2C		600	0.54	230	46	10	24	34
8C		600	0.72	240	39	10	34	50
12F		600	0.68	170	95	9	48	32
1E	200	200	0.76	260	39	10	33	38
8F		200	0.86	200	40	9	29	38
11B		200	0.84	800	53	10	42	67
1F		400	0.67	900	60	10	35	34
8E		400	0.70	250	40	10	40	38
11A		400	0.67	850	53	9	39	64
1D		600	0.69	200	76	8	37	47
8D		600	0.72	280	68	11	49	47
11C		600	0.62	900	55	10	48	69
4D	400	200	0.59	210	56	11	40	40
6A		200	0.71	650	90	10	78	39
9E[2]		200	0.74	170	164	7	275	41
4F		400	0.63	290	69	11	40	42
6C		400	ns[3]	ns	ns	ns	ns	ns
9F[2]		400	0.99	220	41	9	85	50
4E		600	0.69	300	57	11	40	40
6B		600	0.68	500	190	21	175	44
9D[2]		600	0.65	210	206	11	185	61

[1] No analysis.

[2] No sewage added.

[3] No sample collected.

Table IV-8. Micronutrient analyses of alfalfa harvested in May 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B	Mo	Co
				ppm						
3C	0	0	0.45	320	24	12	20	46	0.5	0.50
6D		0	0.45	280	30	14	24	44	0.5	0.53
10A		0	0.50	220	20	14	40	44	0.8	0.78
3B		0	0.41	220	20	14	20	35	0.5	0.57
6E		0	0.49	120	28	6	42	45	0.6	0.38
10C		0	0.76	540	36	16	22	35	0.6	0.50
3A		0	0.42	180	18	10	20	39	0.6	0.57
6F		0	0.50	260	50	14	22	46	0.5	0.67
10B		0	0.75	200	32	18	26	36	0.5	0.50
2B	100	0	0.59	560	34	12	36	37	1.6	0.40
8A		0	0.48	140	22	12	40	38	1.0	0.50
12E		0	0.72	280	34	20	34	44	0.8	0.63
2A		0	0.41	220	20	12	40	34	1.0	0.43
8B		0	0.37	140	44	na[1]	60	42	1.0	0.43
12D		0	0.57	300	32	16	36	39	1.2	0.46
2C		0	0.53	220	26	2	38	33	1.8	0.42
8C		0	0.18	220	32	14	38	36	0.7	0.60
12F		0	0.75	220	70	16	32	41	1.0	0.50
1E	200	0	0.47	260	22	12	40	46	1.5	0.73
8F		0	0.33	240	38	16	36	32	1.0	0.60
11B		0	0.76	240	24	12	44	56	1.2	0.60
1F		0	0.35	140	18	12	38	26	1.2	0.20
8E		0	0.48	140	28	16	44	31	0.8	0.43
11A		0	0.72	180	22	12	44	41	1.0	0.46
1D		0	0.51	260	34	10	38	35	1.1	0.57
8D		0	0.44	280	30	14	50	32	1.0	0.43
11C		0	0.47	100	20	10	42	30	0.9	0.50
4D	400	0	0.41	300	32	10	46	56	1.2	0.57
6A		0	0.50	200	26	8	54	43	1.4	0.46
9E[2]		0	0.68	180	42	10	128	35	3.0	0.43
4F		0	0.46	240	62	10	64	45	1.6	0.57
6C		0	0.36	120	30	12	70	32	2.8	0.63
9F[2]		0	0.85	200	35	11	66	47	1.1	0.57
4E		0	0.40	140	26	10	50	34	1.2	0.50
6B		0	0.49	140	50	10	108	46	2.2	0.53
9D[2]		0	0.76	170	62	13	102	53	2.5	0.67

[1] No analysis.

[2] No sewage added.

Table IV-9. Micronutrient analyses of alfalfa harvested in August 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Na %	Fe	Mn	Cu	Zn	B
				ppm				
3C	0	0	0.05	140	28	18	28	33
6D		0	0.08	140	28	na[1]	30	45
10A		0	0.06	160	28	12	20	62
3B		0	0.16	160	34	12	na	37
6E		0	0.17	140	50	na	40	50
10C		0	0.13	100	30	6	16	48
3A		0	0.04	160	36	12	24	64
6F		0	0.08	120	38	na	na	48
10B		0	0.08	140	24	10	18	62
2B	100	0	0.08	140	30	14	24	64
8A		0	0.12	200	32	na	48	50
12E		0	0.08	140	28	na	24	41
2A		0	0.05	280	28	na	20	54
8B		0	na	280	36	10	46	45
12D		0	0.16	160	42	na	30	69
2C		0	0.07	120	34	14	34	59
8C		0	0.12	220	36	na	38	45
12F		0	0.13	140	48	na	34	54
1E	200	0	0.12	160	28	na	36	55
8F		0	0.07	160	40	na	44	50
11B		0	0.11	140	26	na	24	57
1F		0	0.08	360	30	na	70	66
8E		0	0.09	140	34	16	42	77
11A		0	0.15	140	34	na	34	77
1D		0	0.10	140	44	na	40	84
8D		0	0.17	180	44	10	52	64
11C		0	0.10	120	36	18	42	80
4D	400	0	0.10	200	32	na	64	77
6A		0	0.11	180	40	8	42	82
9E[2]		0	0.14	120	na	14	102	94
4F		0	0.10	180	48	na	64	91
6C		0	0.15	160	44	na	64	97
9F[2]		0	0.12	100	54	14	72	100
4E		0	0.12	160	30	18	44	64
6B		0	0.10	180	24	na	50	72
9D[2]		0	0.16	140	68	20	68	97

[1] No analysis.

[2] No sewage added.

APPENDIX V

Table V-1. Analyses of surface soil (0 to 6 inches) sampled in April 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
						ppm				
3-4C[1]	0	80	6.3	1.0	0.21	0.61	4.0	25.1	0.73	0.28
5-6D		80	7.3	0.6	0.12	0.45	2.8	8.0	0.80	0.49
9-10A		80	6.8	1.5	0.15	0.55	4.0	14.4	0.71	0.48
3-4B		130	5.7	1.5	0.03	0.54	6.0	30.0	0.72	0.26
5-6E		130	6.2	1.2	0.08	0.57	4.0	22.4	0.82	0.31
9-10C		130	6.5	1.4	0.10	0.58	4.6	19.6	0.68	0.59
3-4A		180	6.1	1.5	0.08	0.65	3.9	36.5	0.64	0.25
5-6F		180	6.8	1.3	0.09	0.56	4.2	21.8	1.02	0.29
9-10B		180	6.0	2.4	0.09	0.62	5.5	28.5	0.77	0.62
1-2B	100	130	5.7	1.1	0.17	1.6	17.5	27.3	1.34	21.4
7-8A		130	5.8	2.0	0.17	1.7	7.2	22.5	1.35	16.7
11-12E		130	6.0	1.2	0.31	1.7	8.4	19.9	1.13	11.4
1-2A		180	5.7	2.0	0.20	2.2	11.5	36.3	1.05	12.4
7-8B		180	5.9	2.2	0.19	1.8	7.8	18.8	1.30	13.4
11-12D		180	5.9	1.6	0.37	1.9	10.8	31.9	1.76	21.2
1-2C		280	6.3	1.5	0.23	1.9	7.6	17.4	1.83	28.4
7-8C		280	5.9	2.4	0.18	1.9	11,7	29.8	1.27	12.9
11-12F		280	5.9	2.8	0.23	1.6	6.4	33.2	1.09	8.4
1-2E	200	130	6.8	2.0	0.31	2.4	10.7	20.4	2.02	36.4
7-8F		130	5.9	2.6	0.32	3.7	21.5	18.0	2.47	38.7
11-12B		130	6.4	2.8	1.28	16.0	57.5	22.5	4.82	73.4
1-2F		180	6.5	2.6	0.40	4.2	27.5	14.5	3.02	37.9
7-8E		180	6.0	2.7	0.37	3.4	36.5	20.5	2.67	30.9
11-12A		180	6.1	2.1	0.43	6.2	11.8	21.1	2.35	30.1
1-2D		280	6.0	3.6	0.26	4.4	26.3	33.1	2.41	94.0
7-8D		280	6.6	3.0	0.29	2.1	22.0	30.5	2.62	30.4
11-12C		280	5.9	3.4	0.77	8.8	24.5	30.0	3.17	41.4
3-4D	400	130	6.4	2.8	1.96	36	290	77.2	12.6	169
5-6A		130	7.3	2.6	3.83	50	115	48.4	na[2]	380
9-10E[3]		130	7.1	1.6	2.50	23	166	48.0	25.4	900
3-4F		180	6.4	3.6	2.43	28	191	55.4	9.5	188
5-6C		180	6.9	3.6	7.13	31	787	130	90.8	630
9-10F[3]		180	7.7	1.4	1.80	33	70	28.5	8.8	1845
3-4E		280	6.6	2.6	1.67	37	95	55.9	5.3	118
5-6B		280	7.2	3.8	6.43	34	219	24.5	16.6	570
9-10D[3]		280	7.1	2.9	3.40	21	168	48.0	37.0	1365

[1] Sample collected from several locations within plots 3C and 4C.

[2] No analysis.

[3] No sewage added.

Table V-2. Analyses of surface soil (0 to 6 inches) sampled in June 1972.

Fescue Plots					Alfalfa Plots				
Plot	Solid waste ton/acre	Nitrogen added lb/acre	pH	B ppm	Plot	Solid waste ton/acre	Nitrogen added lb/acre	pH	B ppm
4C	0	200	7.4	0.28	3C	0	80	8.2	0.32
5D		200	8.8	0.30	6D		80	8.4	0.44
9A		200	8.4	0.49	10A		80	8.6	0.52
4B		400	7.6	0.54	3B		200	7.7	0.64
5E		400	7.4	0.32	6E		200	7.2	0.49
9C		400	6.8	0.57	10C		200	7.5	0.55
4A		600	6.2	0.28	3A		400	6.7	0.32
5F		600	6.5	0.30	6F		400	7.2	0.48
9B		600	6.3	0.54	10B		400	6.9	0.56
1B	100	400	7.2	0.80	2B	100	200	7.5	0.54
7A		400	6.7	0.96	8A		200	8.1	0.79
11E		400	6.9	0.74	12E		200	7.8	0.73
1A		600	6.6	0.82	2A		400	7.0	0.60
7B		600	5.8	0.82	8B		400	6.7	0.78
11D		600	6.2	0.77	12D		400	7.4	0.81
1C		1200	6.2	0.58	2C		600	7.6	0.40
7C		1200	5.3	0.88	8C		600	7.0	0.52
11F		1200	5.3	0.69	12F		600	6.4	0.64
2E	200	400	6.6	0.90	1E	200	200	7.6	0.72
7F		400	6.7	0.64	8F		200	7.0	0.85
12B		400	7.3	1.30	11B		200	7.7	1.41
2F		600	6.3	0.76	1F		400	7.0	0.78
7E		600	5.6	0.76	8E		400	7.1	0.76
12A		600	6.5	1.37	11A		400	7.0	1.81
2D		1200	5.3	0.58	1D		600	6.8	0.78
7D		1200	5.0	0.72	8D		600	6.7	0.92
12C		1200	5.1	0.92	11C		600	7.0	1.70
3D	400	400	6.9	2.02	4D	400	200	7.2	1.48
5A		400	7.3	1.18	6A		200	7.8	2.06
10E[1]		400	7.3	0.79	9E[1]		200	7.2	2.14
3F		600	5.4	1.52	4F		400	6.8	1.54
5C		600	7.1	1.40	6C		400	7.3	4.10
10F[1]		600	6.1	1.26	9F[1]		400	7.3	1.20
3E		1200	5.0	1.96	4F		600	7.0	0.70
5B		1200	5.3	1.52	6B		600	7.1	4.02
10D[1]		1200	5.8	1.84	9D[1]		600	7.5	3.32

[1] No sewage added.

Table V-3. Analyses of surface soil (0 to 6 inches) sampled in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
						ppm				
				Fescue Plots						
5D	0	250	8.2	0.45	0.73	0.48	2.5	7.0	0.70	3.03
4B		500	7.3	0.93	1.19	0.40	14.0	24.5	0.77	0.70
9B		1000	6.9	0.89	1.20	0.21	7.8	23.9	0.90	1.47
1B	100	500	7.2	0.80	1.12	0.60	9.4	18.0	1.77	34.9
11D		1000	6.9	0.58	1.01	0.59	12.8	33.7	1.61	9.9
7C		2000	6.0	0.93	1.11	0.40	21.8	24.2	1.37	8.5
2E	200	500	6.8	2.35	0.71	1.00	11.3	14.1	3.23	45.2
7E		1000	6.4	1.92	0.69	0.50	14.8	19.7	2.11	20.4
12C		2000	5.5	0.82	1.00	0.90	15.5	52.7	2.13	18.4
5A	400	500	7.2	0.70	0.79	1.60	11.5	21.3	2.59	31.9
3F		1000	6.3	0.70	1.46	2.4	45.5	22.3	7.82	97.0
10D[1]		2000	5.4	0.65	0.84	1.68	18.5	69.5	4.82	82.4
				Alfalfa Plots						
6D	0	80	7.5	na[2]	na	0.52	na	na	na	na
3B		200	7.6	na	na	0.54	na	na	na	na
10B		400	7.4	na	na	0.29	na	na	na	na
2B	100	200	7.6	na	na	0.49	na	na	na	na
12D		400	7.3	na	na	0.71	na	na	na	na
8C		600	6.8	na	na	0.52	na	na	na	na
1E	200	200	7.0	na	na	0.84	na	na	na	na
8E		400	7.1	na	na	0.71	na	na	na	na
11C		600	6.8	na	na	0.98	na	na	na	na
6A	400	200	7.4	na	na	2.1	na	na	na	na
4F		400	7.2	na	na	1.7	na	na	na	na
9D[1]		600	7.3	na	na	2.2	na	na	na	na

[1] No sewage added.

[2] No analysis.

Table V-4. Analyses of surface soil (0 to 6 inches) sampled in March 1973.

Fescue Plots					Alfalfa Plots				
Plot	Solid waste ton/acre	Nitrogen added[1] lb/acre	pH	B ppm	Plot	Solid waste ton/acre	Nitrogen added lb/acre	pH	B ppm
4C	0	250	6.5	0.31	3C	0	0	7.5	0.40
5D		250	6.5	0.60	6D		0	7.2	0.53
9A		250	8.0	0.47	10A		0	7.8	0.53
4B		500	6.1	0.39	3B		0	6.8	0.47
5E		500	6.3	0.59	6E		0	7.1	na[2]
9C		500	7.5	0.53	10C		0	7.2	0.50
4A		1000	6.0	0.40	3A		0	6.7	0.45
5F		1000	6.2	0.43	6F		0	6.6	0.40
9B		1000	6.6	0.28	10B		0	7.8	0.50
1B	100	500	6.2	0.64	2B	100	0	6.7	0.71
7A		500	5.2	0.60	8A		0	7.4	0.60
11E		500	6.2	0.68	12E		0	6.9	0.65
1A		1000	6.2	0.46	2A		0	6.8	0.56
7B		1000	5.7	0.92	8B		0	7.2	0.53
11D		1000	5.6	0.71	12D		0	7.0	0.67
1C		2000	5.6	0.48	2C		0	6.9	0.51
7C		2000	5.3	0.71	8C		0	6.7	na
11F		2000	5.7	1.02	12F		0	6.9	0.57
2E	200	500	6.3	0.71	1E	200	0	6.6	0.65
7F		500	6.4	0.64	8F		0	7.1	0.60
12B		500	6.8	0.71	11B		0	7.6	0.74
2F		1000	5.7	0.67	1F		0	6.6	0.62
7E		1000	5.4	0.68	8E		0	7.0	0.64
12A		1000	6.6	0.57	11A		0	6.8	1.05
2D		2000	5.1	0.71	1D		0	6.4	0.69
7D		2000	5.0	0.71	8D		0	6.6	na
12C		2000	5.5	0.73	11C		0	7.0	1.10
3D	400	500	6.5	4.3	4D	400	0	6.7	3.3
5A		500	7.6	2.4	6A		0	7.2	3.6
10E[2]		500	7.0	1.6	9E[3]		0	7.1	2.5
3F		1000	5.8	3.6	4F		0	6.8	2.2
5C		1000	5.8	2.6	6C		0	7.2	4.8
10F[3]		1000	5.9	1.5	9F[3]		0	7.2	2.6
3E		2000	5.2	4.6	4E		0	7.3	2.7
5B		2000	5.3	2.6	6B		0	7.0	3.3
10D[3]		2000	5.5	2.0	9D[3]		0	7.2	4.8

[1] Nitrogen fertilizer applied in 1972.

[2] No analysis.

[3] No sewage added.

Table V-5. Analyses of surface soil (0 to 6 inches) sampled in September 1973.

Plot	Solid waste ton/acre	Nitrogen added[1] lb/acre	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
						ppm				
					Fescue Plots					
5D	0	150	8.6	1.00	1.58	0.43	2.0	6.7	0.70	1.58
4B		300	6.8	1.45	1.26	0.46	16.8	32.4	0.87	1.75
9B		600	6.4	2.60	1.63	0.62	22.5	49.3	1.05	4.20
1B	100	150	7.9	1.4	1.63	0.62	7.5	15.4	1.19	31.7
11D		300	7.4	1.03	1.23	0.76	9.4	13.4	1.47	33.7
7C		600	4.9	2.80	1.55	0.62	34.3	46.5	1.74	8.5
2E	200	150	7.3	1.55	1.67	0.74	9.0	17.5	1.82	28.4
7E		300	6.3	2.0	1.20	0.65	15.9	27.4	1.88	20.2
12C		600	5.3	2.65	1.27	0.72	16.8	67.6	3.03	21.6
5A	400	150	7.4	1.4	1.31	1.4	8.9	13.2	2.35	15.4
3F[2]		300	6.3	1.85	2.48	2.6	138	50.3	8.32	145
10D[2]		600	4.9	1.5	1.14	1.8	37.8	73.8	3.57	36.9
					Alfalfa Plots					
6D	0	0	7.6	na[3]	na	0.46	na	na	na	na
3B		0	8.0	na	na	0.46	na	na	na	na
10B		0	7.2	na	na	0.38	na	na	na	na
2B	100	0	7.7	na	na	0.50	na	na	na	na
12D		0	7.2	na	na	0.67	na	na	na	na
8C		0	7.3	na	na	0.46	na	na	na	na
1E	200	0	7.6	na	na	0.60	na	na	na	na
8E		0	7.4	na	na	0.59	na	na	na	na
11C		0	7.5	na	na	0.91	na	na	na	na
6A	400	0	7.8	na	na	2.1	na	na	na	na
4F[2]		0	7.2	na	na	2.3	na	na	na	na
9D[2]		0	7.5	na	na	2.2	na	na	na	na

[1] Nitrogen fertilizer applied in 1973.

[2] No sewage added.

[3] No analysis.

APPENDIX VI

Table VI-1. Analyses of soil profile samples collected in April and June 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
							ppm				
					April						
5-6A[1]	400	130	0-6[2]	6.9	2.35	2.76	36	190	57.9	19.0	483
	400	130	15-27	8.2	0.91	0.15	0.92	5.3	4.72	1.48	0.74
	400	130	27-40	8.5	0.52	0.03	0.52	4.0	2.70	0.85	0.28
	400	130	40-52	8.4	0.36	0.03	0.48	2.2	0.96	0.55	0.45
	400	130	52-60	8.6	0.36	0.08	0.46	1.8	0.77	0.43	0.32
5-6B[1]	400	280	0-6[2]	7.0	3.08	3.83	31	161	42.8	19.6	684
	400	280	10-20	8.4	0.43	0.18	0.84	5.8	8.50	1.28	0.93
	400	280	20-30	8.5	0.59	0.04	0.58	4.2	2.76	1.42	0.30
	400	280	30-42	8.5	0.56	0.03	0.54	3.2	1.19	0.79	0.21
	400	280	42-51	8.5	0.50	0.05	0.56	2.7	1.23	0.64	0.21
					June						
3A	0	400	0-6	6.9	na[3]	na	0.82	na	na	na	na
	0	400	6-12	8.1	na	na	0.72	na	na	na	na
	0	400	12-18	8.2	na	na	0.74	na	na	na	na
	0	400	18-24	8.5	na	na	0.72	na	na	na	na
3E	400	1200	0-6	5.3	na	na	3.2	na	na	na	na
	400	1200	6-12	6.6	na	na	2.5	na	na	na	na
	400	1200	12-18	8.2	na	na	2.7	na	na	na	na
	400	1200	18-24	8.3	na	na	2.7	na	na	na	na

[1] Sample collected on the plot border.

[2] Averages for surface samples from 3 replicate plots.

[3] No analysis.

Table VI-2. Analyses of soil profile samples collected in September 1972.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
							ppm				
4C	0	250	0-6	8.6	0.42	0.77	0.94	5.4	6.01	0.83	0.50
	0	250	6-12	8.9	0.45	0.55	0.92	4.3	4.21	0.96	0.10
	0	250	12-18	8.9	0.41	0.43	0.98	3.6	4.36	1.50	0.04
	0	250	18-24	9.0	0.60	0.48	1.04	3.9	2.57	1.62	0.02
	0	250	24-30	8.9	0.41	0.52	1.08	4.7	3.40	1.16	0.04
	0	250	30-36	8.6	0.64	0.46	0.78	4.0	1.37	0.70	0.02
9C	0	500	0-6	7.3	0.31	1.19	1.00	11.8	32.5	1.07	1.38
	0	500	6-12	7.1	0.56	0.40	0.82	8.8	17.1	1.43	0.46
	0	500	12-18	8.6	0.40	0.24	0.92	3.6	3.44	1.34	0.54
	0	500	18-24	8.6	0.58	0.33	0.96	4.9	2.71	1.44	0.20
	0	500	24-30	8.4	1.45	0.43	0.81	4.7	0.79	0.89	0.13
	0	500	30-36	8.3	1.15	0.42	0.65	3.8	0.81	0.71	0.26
6C	400	400	0-6	8.0	0.69	0.69	1.20	47.5	18.9	10.3	150
	400	400	6-12	8.3	0.35	0.59	1.30	7.0	20.5	1.89	16.8
	400	400	12-18	8.2	0.35	0.48	0.70	2.6	7.70	1.37	5.00
	400	400	18-24	8.9	0.34	0.38	1.00	3.3	3.13	1.41	0.96
	400	400	24-30	8.5	0.51	0.45	1.18	5.1	2.30	1.34	1.99
	400	400	30-36	8.8	0.54	0.43	1.44	3.0	1.87	1.08	0.15
9D-E[1]	400	200-600	0-6	7.8	0.70	0.75	0.84	27.0	19.0	2.13	32.7
	400	200-600	6-12	7.9	0.45	0.73	1.14	5.0	19.0	1.23	1.31
	400	200-600	12-18	8.7	0.55	0.64	1.18	4.3	12.9	1.37	0.21
	400	200-600	18-24	8.7	0.54	0.46	1.06	4.3	17.8	1.55	0.27
	400	200-600	24-30	8.6	0.81	0.34	1.42	3.8	5.29	1.62	0.24
	400	200-600	30-36	8.3	1.70	0.70	1.60	4.6	2.78	0.89	0.40

[1] Sample collected on the plot border between nitrogen treatments. No sewage was applied to these plots.

Table VI-3. Analyses of soil profile samples collected in March 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	pH	B ppm
9-10C[1]	0	200-500	0-6	7.4	0.40
		200-500	6-12	7.8	0.33
		200-500	12-18	8.3	0.26
		200-500	18-24	8.3	0.30
		200-500	24-30	8.6	0.34
		200-500	30-36	8.7	0.26
		200-500	36-42	8.7	0.30
		200-500	42-48	8.6	0.24
		200-500	48-54	8.6	0.19
		200-500	54-60	8.5	0.27
3-4E[1]	400	600-2000	0-6	5.9	2.8
		600-2000	6-10	6.7	2.9
		600-2000	10-18	8.4	1.9
		600-2000	18-24	8.3	2.6
		600-2000	24-30	8.2	3.4
		600-2000	30-36	8.3	3.2
		600-2000	36-42	8.4	3.6
		600-2000	42-48	8.3	3.6
		600-2000	48-54	8.3	2.3
		600-2000	54-60	8.3	1.4
5-6B[1]	400	600-2000	0-6	7.0	4.4
		600-2000	6-12	7.0	4.2
		600-2000	12-18	7.9	2.9
		600-2000	18-24	8.1	2.3
		600-2000	24-30	8.2	2.0
		600-2000	30-36	8.3	2.0
		600-2000	36-42	8.5	1.7
		600-2000	42-48	8.6	1.6
		600-2000	48-54	8.6	2.2
		600-2000	54-60	8.4	1.5

[1]Sample collected on the plot border between nitrogen treatments.

Table VI-4. Analyses of soil profile samples collected in September 1973.

Plot	Solid waste ton/acre	Nitrogen added lb/acre	Depth inches	pH	Conductivity mmho/cm	Na me/100g	B	Fe	Mn	Cu	Zn
							ppm				
9-10A[1]	0	80-400	0-6	8.8	0.75	1.15	0.32	3.0	9.70	0.50	1.63
		80-400	6-12	8.6	0.41	0.80	0.25	2.4	3.05	0.74	0.36
		80-400	12-18	9.0	0.30	0.76	0.22	2.0	2.74	1.23	0.19
		80-400	18-24	9.1	0.21	0.97	0.19	2.4	2.14	1.30	0.13
		80-400	24-30	8.9	0.94	1.26	0.32	2.6	2.13	1.05	0.08
		80-400	30-36	9.2	0.66	1.46	0.48	4.1	1.95	0.86	0.09
		80-400	36-42	8.7	0.31	0.41	0.27	3.5	1.01	0.63	0.09
		80-400	42-48	8.8	0.34	0.13	0.26	2.1	1.04	0.57	0.08
		80-400	48-54	8.8	0.30	0.11	0.27	1.9	1.25	0.52	0.08
		80-400	54-60	8.7	0.72	0.20	0.33	1.7	1.57	0.86	0.23
5-6A[1]	400	200-650	0-6	8.5	1.01	3.04	2.2	21.0	14.0	3.17	32.9
		200-650	6-12	8.5	1.5	2.13	2.7	19.7	15.0	4.30	64.9
		200-650	12-18	8.4	0.49	0.64	1.9	17.0	9.5	2.15	7.03
		200-650	18-24	8.4	0.53	0.44	1.2	4.0	3.97	1.54	1.24
		200-650	24-30	8.6	0.66	0.31	1.5	5.3	2.73	1.11	0.92
		200-650	30-36	8.6	0.41	0.24	1.1	3.9	1.80	0.65	0.57
		200-650	36-42	8.6	0.69	0.29	0.73	3.1	1.72	0.56	0.45
		200-650	42-48	8.7	0.44	0.20	0.76	2.4	1.43	0.44	0.14
		200-650	48-54	8.8	0.55	0.15	0.89	2.1	1.41	0.42	0.34
		200-650	54-60	8.8	1.38	0.15	0.93	1.9	1.23	0.40	0.18
9-10D[2]	400	600-2600	0-6	7.5	0.59	2.48	4.4	71.3	17.0	11.3	480
		600-2600	6-12	7.9	1.01	1.57	3.5	25.0	15.9	4.60	360
		600-2600	12-18	8.4	1.05	0.83	2.2	10.7	28.4	2.61	59.2
		600-2600	18-24	8.6	1.00	0.76	2.2	5.0	16.2	2.50	12.4
		600-2600	24-30	8.2	1.06	0.93	2.6	4.7	8.4	1.34	1.03
		600-2600	30-36	8.4	1.35	1.21	3.3	5.5	4.76	1.35	6.40
		600-2600	36-42	8.7	0.71	0.67	2.7	2.8	2.09	0.79	3.08
		600-2600	42-48	8.4	0.89	0.36	1.5	2.1	1.01	0.68	2.53
		600-2600	48-54	8.4	0.83	0.21	1.2	2.9	0.96	0.48	1.01
		600-2600	54-60	8.5	0.81	0.20	1.0	1.6	1.63	0.73	2.48

[1]Sample collected on the plot border between nitrogen treatments. [2] No sewage applied.