EPA-600/2-75-034
September 1975

Environmental Protection Technology Series

TRENCH INCORPORATION OF SEWAGE SLUDGE IN MARGINAL AGRICULTURAL LAND

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
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TRENCH INCORPORATION OF SEWAGE SLUDGE IN MARGINAL AGRICULTURAL LAND

by

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Program Element No. 1BB043

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DISCLAIMER

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

This report describes an approach for the recycling of valuable resources in sludges from biological wastewater treatment plants and indicates the potential beneficial effect of the recycling on part of the biosphere. The report also summarizes a study of the effect of environmental contaminants in the sludge on the biosphere.

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ABSTRACT

Entrenchment is a feasible method for simultaneously disposing of dewatered sewage sludges (15-25% solids) and improving marginal land for plant growth. The primary problem is to avoid pollution of groundwater with nitrate-nitrogen. Recommendations are given for running a sludge trenching operation. In the study, application rates were 800 and 1150 metric tons/hectare (350 and 500 tons/acre) dry solids, respectively, in trenches 60 cm (2 feet) wide x 60 cm deep x 60 cm apart and 60 cm wide x 120 cm deep x 120 cm apart.

Entrenchment prevented contamination of surface water, buried pathogens permitting their demise during sludge decomposition, promoted slow nitrogen release, and favored denitrification.

Nineteen months after sludge entrenchment, fecal coliform and salmonella bacteria had not been detected in sandy soil more than a few centimeters from the entrenched sludge. No significant downward movement of heavy metals had been detected, and metal uptake by crops had been moderate. Nitrate movement had occurred, causing increased levels in underdrained water. Groundwater in monitoring wells did not show increases in any pollutants that might have come from the sludge except chloride.

The Agricultural Research Service, in cooperation with the Maryland Environmental Service and the District of Columbia, has submitted this report in partial fulfillment of Contract No. 68-01-0162 under the partial sponsorship of the Environmental Protection Agency. The report covers research work conducted from January 1972 to January 1974.

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ACKNOWLEDGMENTS

We gratefully acknowledge the considerable efforts of many individuals and organizations who have contributed significantly to the project described herein. In particular, we acknowledge the help and support of officials and citizens of Prince Georges County, the District of Columbia, the Maryland Department of Health and Mental Hygiene, the Maryland Department of Natural Resources, and the EPA Municipal Environmental Research Laboratory, Cincinnati, Ohio.

Cooperating scientists and support personnel in ARS who have contributed include: J. O. Legg, W. D. Kemper, J. V. Lagerwerff, J. M. Taylor, N. K. Enkiri, A. V. Gibson, L. E. Gross, J. B. Munns, A. R. Kaminski, M. L. Terwilliger, M. R. Peters, and S. M. Hoffman. Support personnel employed by MES on the work have been: M. C. White, J. C. Baxter, D. Mosher, L. C. Olver, T. L. Lathan, W. T. Palmer, and J. Marmelstein. Also acknowledged is the work of W. H. Harrington and R. H. Becker or Whitman, Requardt, and Associates.

SECTION I

SUMMARY AND CONCLUSIONS

GENERAL

Research and demonstrations in the field and laboratory have shown that digested and limed undigested (raw-limed) dewatered sewage sludges (18 to 25% solids) can be incorporated into soil in small closely spaced trenches without odor problems or the hazard of surface water runoff. In the field approximately 1 hectare (2.5 acres) was trenched and filled with the dewatered and liquid sludges in test plots in 2 hectares of a 10-hectare watershed.

DRAINAGE AND WELLS

The water table of the test area was determined by drilling 40 test wells. Drain lines and diversion ditches were installed to carry groundwater and surface water from the entrenchment area into a 0.4 hectare (1 acre) pond constructed to hold 3750 cubic meters (1 million gallons) of water. The 40 test wells were also used to monitor the entrenchment site and adjacent areas.

TRENCH SPACING AND SLUDGE APPLICATION RATE

Dewatered sludges (20 to 25% solids) were placed in trenches that were either 60 cm (2 feet) wide by 60 cm deep by 60 cm apart (60 x 60 x 60 cm) or were 60 x 120 x 120 cm. Resulting rates of dewatered sludge application in the filled trenches were approximately 800 and 1150 dry metric tons/hectare (350 and 500 dry tons/acre) respectively.

Limed liquid undigested (raw) sludge (5 to 8% solids) was placed in trenches that were 60 x 120 x 240 to 320 cm. The wider spacing between trenches was necessary because of the instability of the sandy soils when the trenches were half filled with liquid sludge. If more than half filled, sludge would overflow from trenches when backfilled with soil. The resulting rate of liquid sludge entrenchment was 125 dry metric tons/hectare (55 dry tons/acre).

HAULING AND INCORPORATION

While dump trucks and front-end loaders were successfully used to haul, move, and place large amounts of sludge in our test plots, the method produced considerable soil surface contamination, and equipment bogged down during rainy weather.

The trencher used for the simultaneous digging of the trenches and covering of the trenches previously filled with sludge was generally satisfactory. Some slippage of the trencher occurred but the addition of cleats to the metal tracks should minimize the slippage. Narrow spacing between trenches was possible because of the digging mechanism which was moveable from side to side behind the metal tracks.

TILLAGE

The plots were either left in ridges; leveled and disked; or leveled, disked, and cross-ripped. There was no apparent harm in leaving the area ridged for a time, but it was difficult to establish a satisfactory ground cover on the ridged soil even by hydroseeding. Ripping the sludge at right angles to the trenches did not cause significant subsurface mixing of sludge nor did it improve crop growth. Because of the softness of the area, a tracked vehicle was needed to pull the ripping equipment. Leveling the ridges over the trenches left a layer of soil 28 to 35 cm (10 to 15 inches) thick over the sludge and original soil surface. This soil covering had to be limed and fertilized or treated with digested sludge at a rate of 35 to 60 dry metric tons/hectare (15 to 25 dry tons/acre) prior to seeding to establish a crop. Irrigation was also necessary on this very sandy soil.

It was very difficult to cultivate the area in which the liquid sludge was entrenched because of the wet soil conditions.

CROP GROWTH

Kentucky-31 tall fescue grass, corn, soybeans, alfalfa, and fruit and shade trees were successfully grown on the test plots. Corn growth was initially inhibited by the recently entrenched sludge because of high concentrations of ammonia, low concentrations of oxygen, and the presence of unidentified volatile compounds. This initial toxic response was not apparent in tall fescue.

Crop growth was poorer where sludge was deeper below the surface and where spaces between trenches were greater. Growth was particularly poor on the limed liquid undigested sludge plots where the spacing between trenches was 240 to 300 cm (8 to 10 feet).

NITROGEN

Analyses of well waters did not show increased concentrations of nitrate or ammonium nitrogen, and concentrations of these two nitrogen forms in the holding pond have not exceeded drinking water standards. Comparatively, in part of the underground drainage water which empties into the pond, nitrate levels have steadily increased to levels above drinking water standards. Probably subsurface water with low levels of nitrate and ammonium nitrogen have also been entering the pond and causing some dilution. It is not known whether there has been loss of these two forms of nitrogen by some other mechanism. The pond water has been discharged directly into normal drainage channels because of continued high quality of the water. Irrigation equipment is available for land treatment of the pond water if its quality degenerates.

There was evidence of increasing movement of nitrogen downward from the entrenched sludge with time. As plant roots penetrated, the sludges became more aerobic which allowed nitrate to form, less denitrification to occur, and more water to leach through, carrying the nitrate along. Entrenched sludges were aerobic first on the top and later on the sides as roots penetrated and dewatered the sludge. A much slower rate of sludge dewatering occurred in the absence of roots.

Denitrification of the nitrate to nitrogen gas apparently occurred to the greatest degree under the 60-cm deep limed undigested (raw-limed) sludge trench. While nitrate-nitrogen concentrations were greatest in the raw-limed sludge, there was less nitrate-nitrogen 30 to 60 cm below in the soil than under the 60 cm deep digested sludge trench.

Biological denitrification requires an organic energy source and low oxygen levels. Greater levels of organic materials moved into the soil from the raw-limed than from the digested entrenched sludges and provided a greater potential for denitrification. Originally, oxygen concentrations were rather low under the trenches, but they increased as the sludges dewatered.

There has been little nitrogen movement from the digested 120-cm deep trenched sludge. Digested sludge in the 120-cm deep trenches has not dewatered to as great an extent as in either the raw-limed or digested 60-cm deep trenches. Thus, any small amount of nitrate that may have formed was not subjected to much leaching and probably was denitrified.

It is not known how much nitrogen may later move from the 120-cm deep trenches as more dewatering of the digested sludge occurs or how fast the dewatering will occur. From the standpoint of nitrogen movement and loss after 18 months of study, digested sludge should be placed in the deep trenches. From a crop benefit standpoint, however, the 60-cm deep trenches with the 60-cm spacing between the trenches was best. In the soil at the test site it was not advisable to narrow the spacing between the 120-cm deep trenches more than the 120-cm edge to edge spacing used because of potential trench wall collapse, when digging and filling.

In contrast to the 120-cm trenches filled with digested sludge, nitrate-nitrogen movement was appreciable under a 120-cm deep raw-limed liquid sludge trench. Here there was close contact between the soil and sludge. This promoted rapid microbial conversion of the sludge nitrogen to the mobile nitrate form. Conditions for appreciable loss of nitrogen by denitrification were apparently unfavorable.

CHLORIDES AND CONDUCTIVITY

Elevated chloride concentrations, but still within drinking water standards, were detected in 3 of 40 test wells. These chlorides apparently came from the entrenched sludges. Elevated conductivities, indicating increased salt concentrations, were detected sporatically in several of the wells and may have resulted from surface contamination rather than from contamination from entrenched sludges.

Chloride moves through the soil at about the same speed as nitrate. While chloride is immediately present in sludge, nitrate must be formed biologically. Furthermore, nitrate can be lost to the atmosphere by denitrification. Therefore increases in chloride concentrations appear to be a good indicator of the potential contamination in groundwater from entrenched sludge, but increases in chloride concentration does not necessarily mean that nitrate contamination will follow.

PATHOGEN MOVEMENT

There was no detected movement of fecal coliform or salmonella bacteria out of the entrenched sludge into the surrounding soil or down to the groundwater. Since viruses were not detected in the entrenched sludges, movement of viruses from the trenches in the field was not measured.

The movement of polio and bacterial viruses with percolating water was studied in the laboratory utilizing disturbed columns of the coarse-textured soil from the trenching site. The soil columns were capable of removing large quantities of viruses from percolating water, but rapid leaching of the columns after application of large quantities of viruses resulted in some virus transport through the columns. From the results of the column studies, the quantities of water required to move viruses in a similar way in the field to a water table at 150 cm (5 feet) of depth greatly exceeded that expected in normal rainfall events. Subsequent adsorption of any dispersed virus by the soil should limit further movement during later rainfall events.

Viruses have been found even in anaerobically digested soil sludge by a number of investigators, but the quantities present are much lower than the amounts applied to the soil columns in our studies. Thus if all the viruses were released from a sludge applied to soil in this study, the relatively great amount of adsorptive soil surface would preclude viruses reaching the groundwater under any reasonable rainfall pattern. Other adsorption studies, in our laboratory, however, have shown that not all soils are capable of adsorbing viruses. As an added precaution against viruses moving into groundwater, an entrenchment site should be chosen that contains a soil capable of adsorbing viruses. The mechanism of virus sorption as yet has not been defined for soil and is under study.

PATHOGEN PERSISTENCE

Liming raw sludge to a high pH decreased tremendously the numbers of salmonella and fecal coliform bacteria. Several months after entrenchment, the sludge pH dropped and these organisms increased in number. This increase was only temporary and their numbers soon began to decrease with time. Salmonella bacteria persistence was for less than 10 months. Total and fecal coliforms greatly decreased in numbers with time, but low levels of these organisms were still found after 2 years. While only the salmonella bacteria are pathogens, their potential for producing disease due to their presence in the trenches in a well managed site should be extremely low. We did not measure persistence of other human pathogens in the entrenched sludge. Most human pathogens, once reduced to very low numbers by liming or some other process, cannot reproduce outside the human host.

HEAVY METALS

The metal contents in samples of sludge composted over 24-hour periods at Blue Plains varied considerably over the 2-year period covered by this study (zinc - 1610 to 2340 ppm, copper - 650 to 720 ppm, nickel - 46 to 94 ppm and cadmium - 13 to 24 ppm). On the other hand variation in metal contents of 24-hour composites taken over a one week period were very small. Variation in the metal content of individual grab samples of sludges taken at different times during 24-hour periods were of the same order of magnitude as the variation observed in the composted samples over the two-year period. Hence, it is necessary to think in terms of average metal content in sludges. Metal concentrations determined in a properly taken 24-hour composite sample were a good representative average.

There was essentially no movement of zinc or copper out of entrenched raw-limed sludge. On the other hand, some movement of zinc occurred from the shallow but not the deeper digested sludge trenches. This movement of metals from the shallow entrenched digested sludge seemed to be associated with aerobic decomposition of the sludge accompanied by oxidation of large quantities of ammonium to nitrate and a resulting reduction in pH of the sludge and surrounding soil.

Heavy metal uptake in the crops from the entrenched sludges did not seem to be excessive in preliminary tests. For example, zinc contents in fescue were 91 ppm growing over 60-cm deep digested sludge trenches, 31 ppm growing over 60-cm deep raw-limed sludge trenches, and 50 ppm in an entrenched control area without sludge. The lower concentrations of heavy metals and the elevated pH which insolubilized metals probably was responsible for less uptake by fescue from the entrenched limed undigested sludge relative to the digested sludge. Relative to the control, the lower uptake may have been a result again of the higher pH which insolubilized metals. Also sludge phosphates and organic matter may have sequestered soil metals making them less available.

As the entrenched sludges became aerobic, DTPA-TEA extractable metals increased. Extractable copper increased 8-fold changing from the sulfite to the sulfate form. Research is underway to determine if metals like zinc and copper become more available to plants as the sludge decomposes in trenches.

In laboratory studies, a wide range of metal tolerances among different species of crops were observed. In general, grasses were most tolerant and absorbed the least amount of metals. Vegetables were least tolerant and absorbed high quantities of metals. Zinc and cadmium were absorbed and readily translocated to plant tops while copper was not. In excess in plants, these metals interfere with iron uptake-transport and cause stunting of plant roots and tops. Soil and sludge pH was the most important single factor affecting metal availability to plants. At pH 7 metals were perhaps ten times less available and toxic to plants than at pH 5. A second important soil factor was cation exchange capacity. At a higher cation exchange capacity, more metals are held and are less available to plants. Hence, trenching sites can be managed to reduce metal uptake by selecting tolerant crops, liming to neutral pH, and selecting soils with higher cation exchange capacities.

TRENCH SIMULATION

Simulated trenches of sludges in boxes permitted detailed studies over a shortened time period. The results revealed (a) more rapid root penetration by corn roots into digested than raw sludge, (b) an anaerobic period in the entrenched sludges and in the soil below prior to root penetration, (c) little, if any, water movement directly through entrenched sludge before dewatering by roots or shrinking and cracking, and (d) the likely occurrence of denitrification in digested and raw sludge with less nitrification and/or greater denitrification under the raw than digested trench.

There was considerably more ammonium movement out of raw-limed trenches in the laboratory than observed in the field. This possibly resulted from irrigated water dissolving ammonium at the sludge surface and then bypassing the soil below by moving through the box soil interface.

As in the field there was little if any movement of metals out of entrenched sludge. Fecal coliform and salmonella bacteria, which have the ability to grow outside their hosts, grew to detectable levels in the high pH sludges only after the sludge pH decreased.

LIMING SLUDGE

Liming sludge at the time of dewatering at the wastewater treatment plant to a pH of approximately 11.5 was desirable because it reduced the levels of pathogens in the sludge. Liming was also desirable because movement of metals out of entrenched sludge into soils was minimized, and metal uptake by plants was reduced. In addition to these process effects, lime is needed in most of our Eastern United States' soils for good crop growth.

ESTIMATED COSTS

The costs for entrenching dewatered raw-limed sludges obtained from Blue Plains during interim treatment (400 filter cake tons per day) were estimated by a consulting firm. Operating and capital costs were estimated at approximately $10.00 per filter cake ton ($50.00 per dry ton) with capital costs amortized over a 2-year period. The costs did not include sludge transport.

SECTION II

RECOMMENDATIONS

GENERAL

Trenching is a suitable procedure for high rate disposal and application of sewage sludge to land. Trenching is an appropriate system to use when low-rate (fertilizer-rate) surface application of sludge is not feasible, e.g., with undigested (raw) sludge. Properly used, trenching is environmentally safe and compatible with use of the land for some agricultural purposes. Trenching is not appropriate in some prime agricultural land because of subsoil being brought to the surface and the amount of trace elements applied. However, since the effects of trenching have been studied for a short time under limited conditions, any immediate plan to use trenching in large scale land application of sludge should include careful monitoring.

DESIRABLE SITE CHARACTERISTICS

A good site should have: a deep water table or a substratum suitable for establishment of a drain system, a good location for a holding pond, good vehicular access, a rural location as near to the sludge source as possible, slopes less than 10 to 15 percent where sludge is to be applied, and soil of marginal agricultural value -- first choice would be a heavy soil underlain with an impermeable stratum. Sites with sandy soils may be helpful for wet weather operations. It also may be necessary to construct temporary field roads and to pump sludge for all weather operation. If fissured rocks are present, they should be at least three meters (ten feet) below the surface.

SURVEY

To determine its suitability, the potential trench application site must be studied carefully to characterize: (a) the surface and subsoil pH, texture, and cation exchange capacity; (b) the topography; (c) the distance to fissured rock; (d) location of any hard, impervious layers; (e) location of permanent and perched water tables; (f) the direction and flow of underground waters; (g) potential for underground drainage; (h) areas for suitable waterholding ponds; and (i) adequate access for heavy trucks and other field equipment; and (j) test trenches to determine ease of digging and side wall stability.

SITE DRAINAGE

When the water table is shallow, as a minimum safety precaution, a perimeter drainage network should be installed with an average depth of 120 to 150 cm (4-5 feet). In climatic areas with appreciable rainfall, pond storage capacity should be able to hold drained water for approximately two months. If contaminated, the water could be applied on surrounding land for purification by crop utilization and percolation through soil. Drainage and surface water control should be under the guidance of an agency like the Soil Conservation Service.

TRENCHES

Trenches should be dug on the contour. The trenches should then be covered the same day that they are filled. A trenching machine should have cleated tracks and a rear-mounted digging wheel that is movable from side to side and tiltable. For maximum benefit and decreased nitrate hazard, limed sludges should be placed in trenches no more than 75 cm (30 inches) deep and 60 cm (24 inches) wide and 60 to 75 cm (24 to 30 inches) apart edge to edge. Sludges placed in narrow trenches (less than 60 cm (24 inches) wide) would result in greater soil sludge contact and more aerobic conditions. Narrow trenches would probably favor more rapid nitrification with less denitrification, and consequently increase the danger of nitrate pollution of groundwater.

SLUDGES

Dewatered sludges should be entrenched at high disposal rates (350 dry metric tons/hectare) when surface application and mixing into the soil surface at fertilizer or soil conditioning rates (25 to 125 dry metric tons/hectare) is not possible. The low-rate application of sludge to the soil surface compared with high-rate application in trenches would yield better agricultural benefit of sludge nutrients and avoid the potential movement of nitrate and excessive metal accumulation in soils.

Undigested primary or secondary sludges should first be limed and dewatered before entrenchment. The pH of the sludge at dewatering should exceed 11.5 to reduce survival of pathogens and to lower the potential for metal accumulation by crops. The metal content of sludges should be known and be as low as possible to further decrease potential for excessive uptake of metals by crops.

Undigested sludges unless stabilized should not be applied to land except in trenches because of the potential pathogen hazard and odor problem associated with surface incorporation. Metal content is less, and apparently risk of nitrate movement is less from a given volume of undigested than of digested entrenched sludge from the same wastewater treatment plant.

HAULING AND FILLING

A sealed concrete mixer type truck is recommended for hauling the sludge from the wastewater treatment plant to the trench incorporation site. This truck could also then be driven directly to the trenches when the soil is dry and capable of bearing the load. The sludge with up to 30% solids content could then be unloaded from the concrete truck via its own extended discharge chute. In wet weather, the concrete truck could discharge the sludge into a trailer outfitted with a peristaltic type pump. A bulldozer could then pull the high flotation trailer near the trench so that the sludge could be unloaded via the pump through pipe and flexible tubing into the trenches.

PREPARATION FOR SEEDING

To prevent erosion and permit soil stabilization, the trenched area should be left ridged until weather is suitable for leveling and seeding. When leveling freshly filled and covered trenches, a bulldozer or some other suitable tracked vehicle should be used at right angles to the trenches. Deep cross-ripping of the entrenched sludge is unnecessary in sandy soil. Its possible benefit should be determined in clay soil. Based on soil tests and the crop to be grown, fertilizer and lime should be applied and worked into the soil surface. The lime and fertilizer requirement could be reduced by surface application of approximately 25 to 60 dry metric tons/hectare (10 to 25 dry tons/acre) of digested dewatered sludge.

CROPS

Crops should be limited to grass the first year. Initially the trenches can be leveled and cultivated only at right angles. If row crops are subsequently grown, they should be planted on the contour to prevent excessive erosion. Because of uncertainty on availability of metals to crops grown on trenched soils, the crops should not be used as food until analyzed to determine their safety.

MONITORING

Since little is known about the long-term effects of trenching on the environment, monitoring for environmental impact of large-scale trenching operations is essential and should be the responsibility of a qualified trained individual working for a governmental institution, such as the State Department of Health. Until long-term background data is accumulated, monitoring should begin before sludge is applied and continue for at least five years after application. The suggested level for classification as a large-scale operation is 10 tons of sludge (dry weight basis, population of 100,000) or more per day. Monitoring needs for small-scale operations (less than 10 dry tons per day) would be very site specific. Thus the monitoring requirements for small operations should be determined on a case by case basis and should be proportional to the magnitude of the specific local environmental risk.

For large-scale operations background samples should be taken from strategically located groundwater wells a month or two before sludge is applied. These wells should be located both inside and on the down flow side of the underground water coming from the entrenchment site. The minimum background analyses should include some of the following determinations: fecal coliforms, PCB's, chlorinated hydrocarbon pesticides, alkalinity, organic nitrogen, nitrate-nitrogen, ammonium-nitrogen, chlorides, pH, COD, zinc, cadmium, copper, and specific conductivity. A similar analysis of the critically located wells for the background parameters should be made 6 to 12 months after sludge incorporation and then yearly for at least five years if contamination is indicated. Water in all wells should be sampled monthly to trimonthly depending upon location, and analyzed for chloride and nitrate-nitrogen. Increased concentrations of chloride would probably be the first indicator of sludge contamination in wells.

At least two sets of background analyses, preferably at three-month intervals, may be made of some of the residential wells located within perhaps a 1.6 kilometer (one mile) radius of the area of sludge entrenchment.

Composite samples should be collected and analyzed from streams draining the area, from major subsurface collector lines draining the area, and from ponds holding drainage water. This sampling should begin two months before sludge application, continue at monthly intervals thereafter, until one year after all sludge has been incorporated, and then periodically for two to four years. Minimum analyses of these samples should include fecal coliforms, pH, dissolved oxygen, COD, chloride, and nitrate-nitrogen.

Before sludges are entrenched, they should be continuously monitored during each day for pH at the treatment plant. At the time of dewatering the pH should exceed 11.5.

Crops grown on the trenching area should be sampled and analyzed annually for at least five years for uptake of zinc, copper, cadmium, nickel, lead, and mercury. The same crops grown on nearly similar soils should be similarly analyzed as a control.

RESEARCH

A portion of the funds for trenching operations should be allocated for research to determine the environmental effects of even larger scale trenching operations than previously studied. Research should be directed to determine the hazards of surface and ground water pollution caused by using various kinds of sludges in various types of soils and to obtain the optimum trench dimensions for maximum leaching with minimum damage to the environment. More information is needed on how these factors influence pathogen survival and movement, nitrogen mineralization and movement, the fate of sludge borne trace elements toxic to plants and animals, and the growth of crops.

SUMMATION

These recommendations on trenching procedures are based on data from experiments over a relatively short time. We believe, however, that this research shows that dewatered sludge can be trenched safely by following our present recommendations. The most likely difficulty is that excessive nitrogen from the sludge might reach underground water. This nitrogen problem can be minimized by underdraining the entrenchment site and retaining the drained water for irrigation of surrounding land or by choosing soils through which movement is minimized.

SECTION III

INTRODUCTION

The lack of acceptable procedures for sewage sludge disposal limits the effectiveness of wastewater treatment.

In general better wastewater treatment generates more sewage sludge requiring disposal. The situation at the Blue Plains wastewater facility, which serves two million people in the Metropolitan Washington, D.C. Area is a good illustration.

Federal regulations require that Blue Plains institute interim and ultimately advanced wastewater treatment to reduce the solids entering the Potomac River in its treated effluent. The Blue Plains plant treats approximately one million cubic meters (300 million gallons) of wastewater per day and, in 1971, generated between 200 and 300 tons (40 to 60 tons of solids) per day of digested sewage sludge. This was combined sludge, from primary and modified waste activated (secondary) treatment of the wastewater, which had undergone high rate anaerobic digestion for an average of 14 days at 35°C (95°F). This combined sludge before digestion will be referred to as raw or undigested sludge in this report, and after anaerobic digestion as digested sludge. By instituting full interim treatment (addition of chemicals to remove phosphate as well as solids), the amounts of raw sewage sludge generated would at least triple. With full advanced treatment, raw sludge levels will increase even further.

Prior to 1973, the Blue Plains plant digested and then held their digested sludge on a drying field before ultimate disposal on land. The field has since been used for new plant construction. Additional digestors are not being built because incineration was the planned method of sludge disposal when full advanced wastewater treatment was realized. Blue Plains has been unable to institute interim treatment on any regular basis because environmentally and/or politically acceptable alternatives did not exist for disposal of the resulting raw sludges. Disposal in landfills has been prevented because sites are unavailable and because landfilling raw sludge in large quantities is particularly difficult.

The District of Columbia Government (DC); the Environmental Protection Agency (EPA); the Maryland Environmental Service (MES); and other State, County, and local agencies and groups launched a cooperative effort with the Agricultural Research Service (ARS) of the United States Department of Agriculture, to find an environmentally acceptable procedure for sewage sludge disposal that also is beneficial to soil and crops. Early in 1972, ARS scientists, in cooperation with these other agencies, began a comprehensive research-demonstration study on evaluating the trenching of raw and digested sewage sludge as a means of improving the agricultural potential of marginal soils and at the same time providing an economically feasible, environmentally sound, and politically acceptable alternative for sewage sludge disposal. These studies included: (1) large-scale field trial to determine feasible all-weather procedures for hauling and incorporating sewage sludge into the soil in trenches; (2) characterization of the site prior to treatment with respect to its hydrologic properties and the biological and chemical properties of the surface and underground water and the soils; (3) testing of a drainage control system for the site; (4) establishment of a monitoring program by which the movement, form, persistence, etc., of sludge nitrogen, heavy metals (zinc, copper, cadmium, nickel, etc.) and pathogens could be followed in ground and surface water and in plants growing on the site after sludge incorporation into the soil; and (5) supportive laboratory and greenhouse studies.

This cooperative project was formally initiated on April 20, 1972, by signing of Contract No. 72374 between Maryland Environmental Services (MES) and the Government of the District of Columbia (DC), and Cooperative Agreement No. 12-14-100-11, 191(41) between MES and the Agricultural Research Service (ARS). The research covered in this report was conducted from January 1972 to January 1974.

SECTION IV

FIELD ENTRENCHMENT OF SLUDGE

SITE CHARACTERISTICS

The experimental site was selected only after inspection of several possible sites. The 35-hectare (75-acre) site selected offered excellent possibilities for soil improvement by sludge entrenchment, for monitoring, and for drainage control. It was readily accessible to heavy equipment, distant from residential development, and because of its very sandy textured soils offered a sensitive test for movement of pollutants from entrenched sludge into the groundwater.

Survey of Groundwater and Underlying Impervious Clay

Beginning in December 1971, about 50 soil borings were made by the Maryland Department of Natural Resources. Thirty of these borings were used to map the water table and underlying impervious clay layers. About 40 were later used as access wells into the groundwater for study of possible contamination from the sludges. Pertinent boring data used to locate drain lines, pond, and sludge incorporation sites are given in Table 1. The locations of approximately 25 wells are shown in Figure 1. Water tables below the plot sites varied approximately as shown in Table 1. The water table remained quite high during 1972 because of the unusually high amounts of rain.

The water table and underlying impervious clay layers are shown in Figure 2.

Tile Drainage and Pond Installation

Based upon the groundwater profile in Figure 2, diversion drains were installed along the east and west edges. A drainage catchment pond was also constructed down slope with sufficient capacity to hold about one month's normal drainage from the site. Location of drains and pond are shown in Figure 1.

Test ditches showed that because the soil was so sandy (Table 2) and wet, open ditches for conventional tile laying would collapse. Therefore a special trenching machine was used with shields behind the trenching wheel. This machine from Robert Vincent Company, Inc., automatically laid a 10- or 12.5-cm (4- or 5-inch) corrugated slotted plastic drain tube (Figure 3). A laser beam guidance system permitted accurate placement of the line on a 0.1 and 0.2% grade. Before the drain tube was installed it was wrapped with a fine-mesh polypropylene screen (polyfiber "GB") to prevent sand-clogging. Plastic drain tubes with screening as part of the fabrication have become available commercially since the installation of the drainage system.

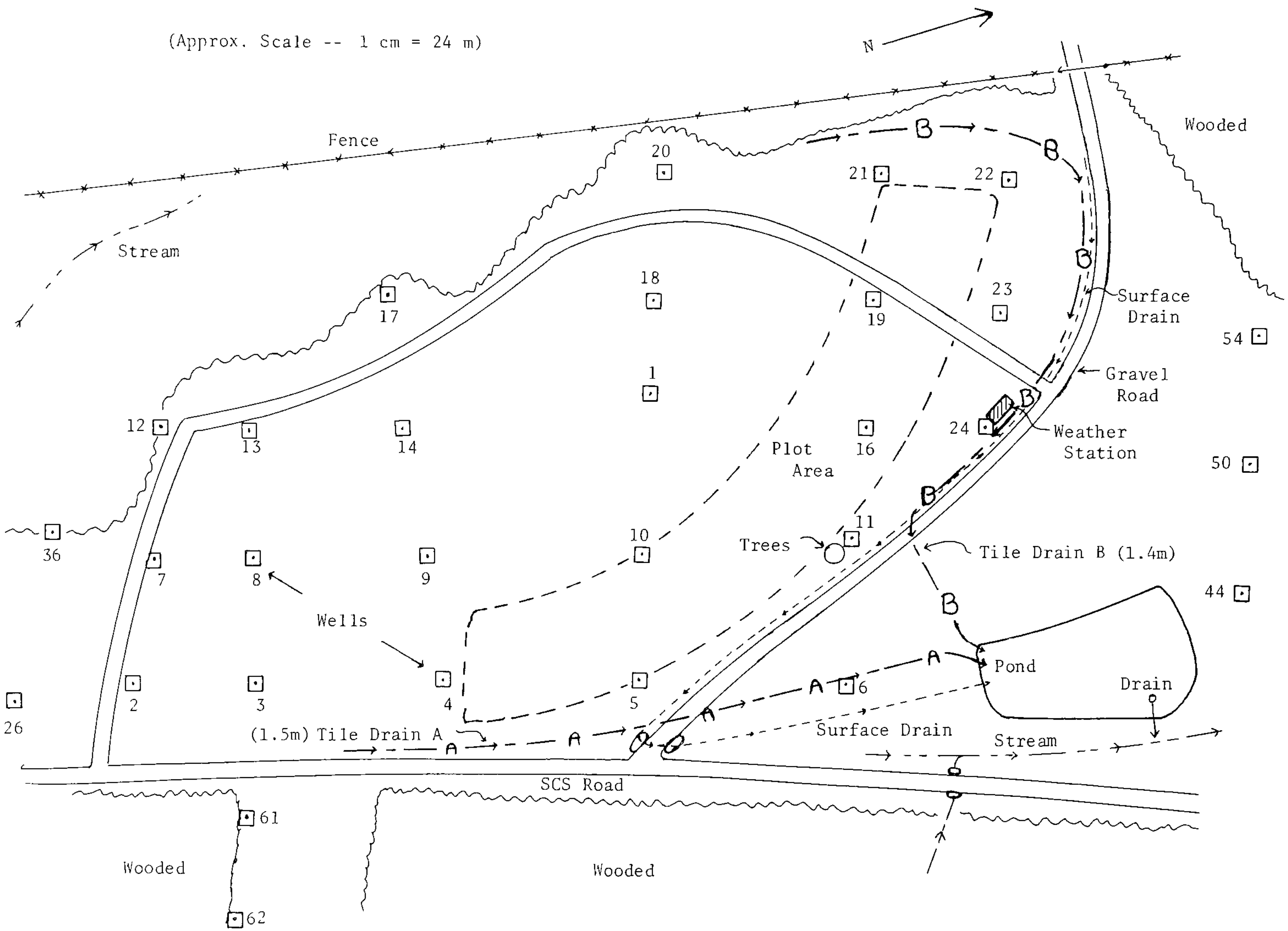
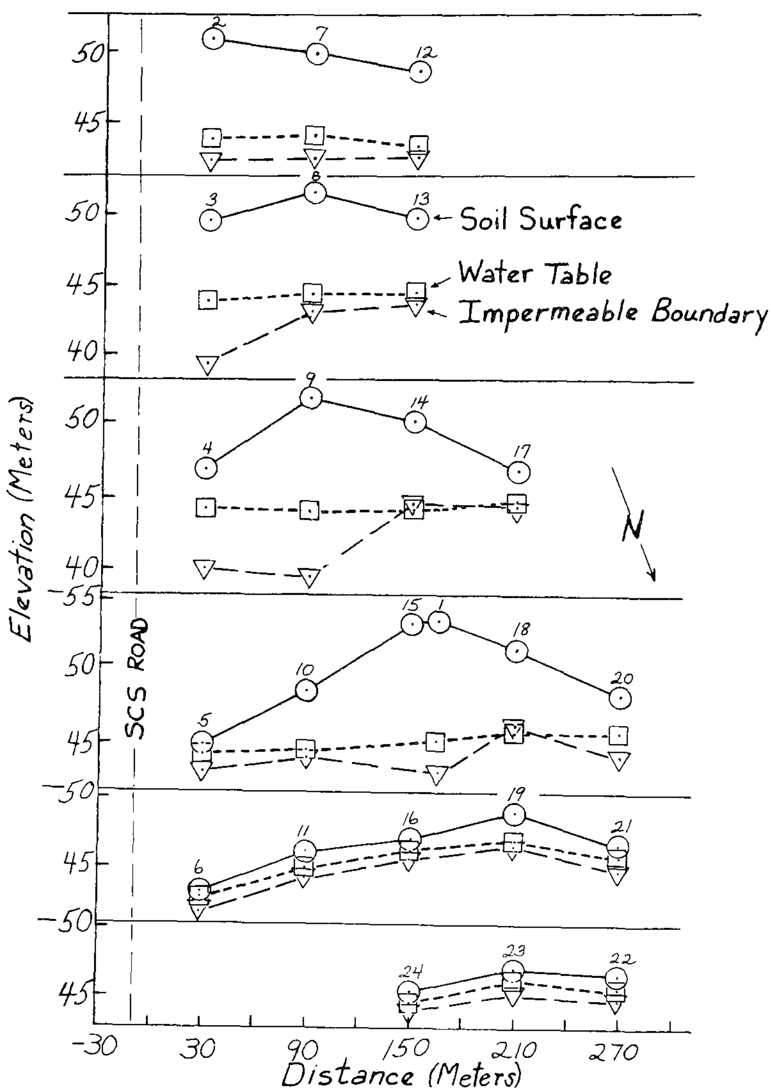
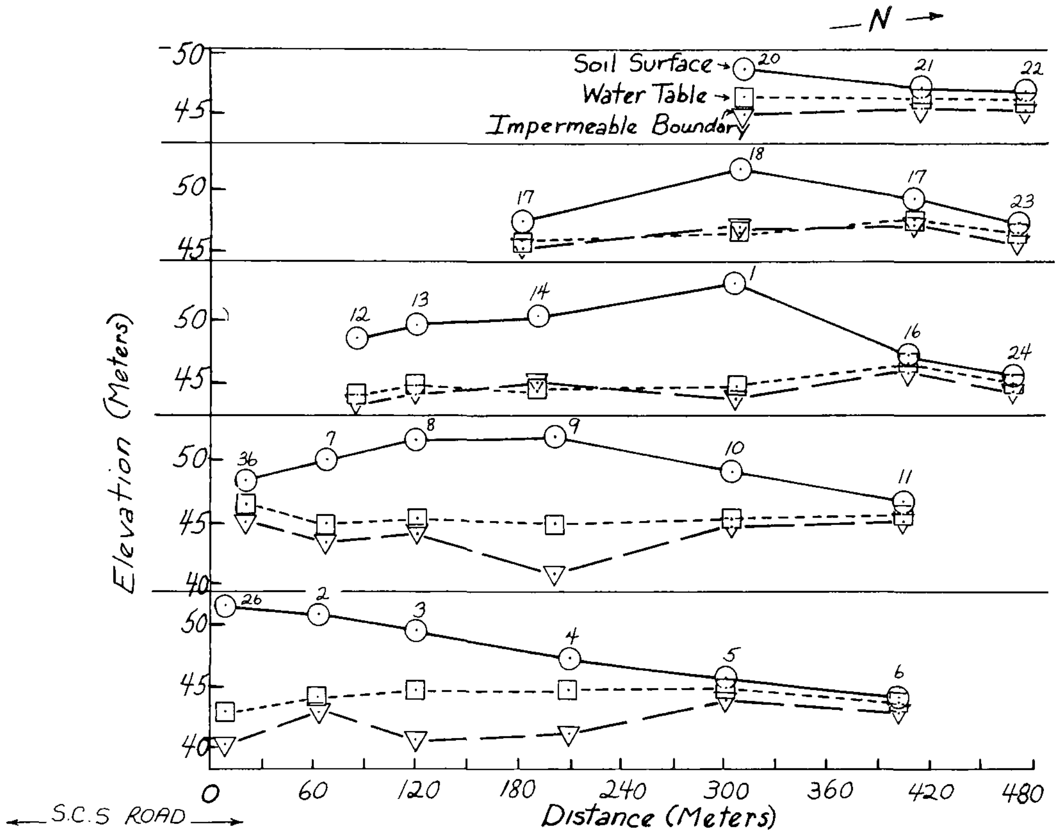


Figure 1. Partial site map.



(A) East-West

Figure 2. Soil surface, water table, and impermeable soil boundary locations determined in January 1972.



(B) South-North

Figure 2 (continued) Soil surface, water table, and impermeable soil boundary locations determined in January 1972.

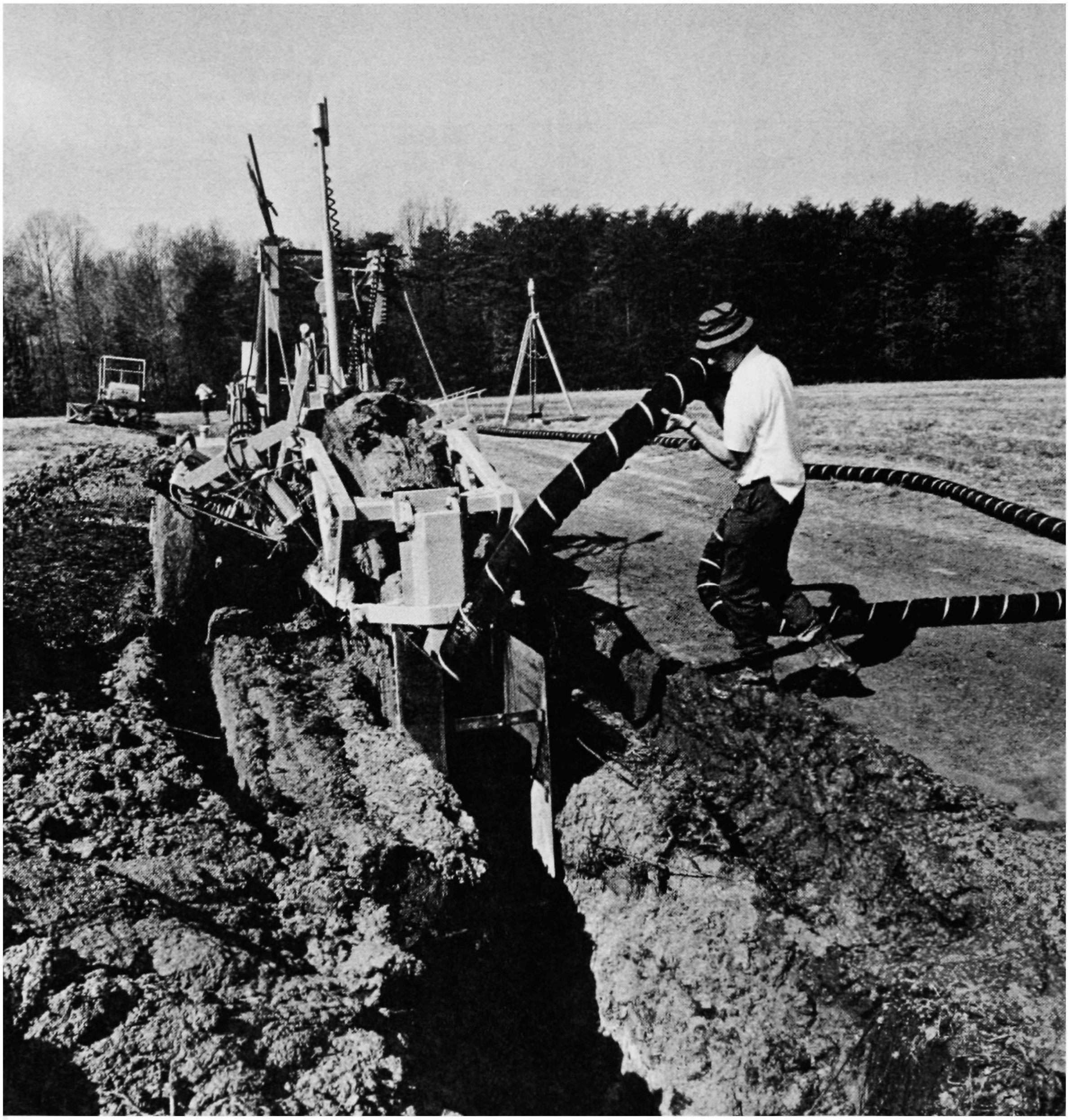


Figure 3. Tile installation

Table 1. GROUNDWATER WELLS - DEPTH AND WATER LEVELS - 1972-1973

Well* No	Depth in meters: To bottom	To impervious layer	Of grout**	To water surface: Jan 72	June 72	Oct 72	Jan 73	June 73	Oct 73
1	13.4	11.2	4.3	9.0	9.1	9.8	9.1	8.9	9.6
2	10.4	9.1	3.0	8.2	8.0	8.5	8.1	8.0	8.4
3	8.2	10.7	3.4	5.9	5.9	6.6	6.1	6.1	6.5
4	6.9	7.4	2.4	3.0	3.1	3.8	3.3	3.2	3.7
5	4.4	2.0	2.4	0.8	1.4	1.9	1.2	1.5	1.9
6	1.5	1.4	0.6	0.1	0.2	0.5	0.1	0.7	1.1
7	8.6	8.0	3.0	6.2	5.9	6.7	6.2	6.1	6.7
8	10.2	8.8	3.6	7.6	7.6	8.4	7.8	7.7	8.4
9	10.3	13.4	3.6	8.5	8.5	dry	8.7	8.5	9.1
10	6.9	5.1	2.4	4.6	4.5	5.9	4.6	4.6	4.9
11	4.9	1.9	1.2	1.2	2.0	2.6	1.1	2.2	dry
12	12.2	6.3	2.7	5.5	---	6.2	5.5	5.4	6.1
13	7.3	6.6	3.6	5.7	5.7	6.5	5.9	5.8	6.2
14	8.3	6.2	3.6	6.6	6.3	7.2	6.6	6.5	6.8
16	4.8	1.5	1.2	0.9	1.3	2.0	0.9	1.2	2.1
17	4.8	2.5	1.8	2.3	2.3	3.0	2.3	2.3	3.0
18	7.9	5.7	3.0	6.1	5.9	6.9	6.0	6.0	6.6
19	4.1	2.2	1.8	2.3	2.4	3.6	2.2	2.5	3.4
20	6.2	4.4	2.1	2.7	2.1	3.5	2.5	2.7	3.4
21	3.0	1.9	1.5	0.9	1.4	2.0	0.9	1.3	2.7
22	2.6	1.9	0.3	1.1	1.6	0.9	0.2	1.5	---
23	4.1	1.9	1.8	0.8	1.5	2.3	0.8	1.6	2.8
24	3.8	1.4	1.8	0.8	1.3	1.5	0.5	1.2	2.5
26	14.6	13.3	1.2	10.2	10.1	10.9	10.6	10.3	10.9
28	15.5	0.9	--- +	dry	dry	---	---	---	---
30	16.5	>16.5	--- +	dry	dry	---	---	---	---
31	17.1	?	4.0	---	13.5	13.7	13.7	13.5	13.7
32	5.5	>5.8	3.6	4.6	dry	---	---	---	---
34	8.5	>5.8	3.6	7.5	7.0	7.9	7.4	7.2	7.9
36	5.4	3.8	3.6	2.1	2.4	3.4	2.2	2.4	3.5
61	11.6	10.1	3.0	---	5.7	6.8	6.4	5.9	7.0
62	11.7	11.0	3.0	---	7.6	8.6	8.3	7.8	8.8
63	12.3	>12.2	4.0	---	9.2	10.1	9.9	9.4	10.3
40	5.4	3.7	2.7	---	0.8	0.6	0.3	0.8	2.3
42	4.9	3.7	2.4	---	1.2	2.7	0.5	1.2	4.0
44	4.1	3.4	2.1	---	1.0	0.6	0.2	1.0	2.5
46	5.9	4.6	3.0	---	1.7	0.9	0.5	1.6	3.3
48	5.6	3.0	3.0	---	1.7	2.8	0.4	1.4	4.0
50	13.1	0.1	--- +	---	dry	---	---	---	---
52	4.1	3.7	2.1	---	2.0	3.5	0.8	1.8	3.8
54	4.1	1.4	2.1	---	0.2	0.4	0.1	0.6	1.8
55	4.0	>3.7	2.1	---	1.2	2.0	0.6	1.3	2.8

* See Figure 1 for well location.

** Filled with sand to grouting depth before grouting.

\+ Not grouted.

Table 2. ANALYSES OF SOILS FROM TEST TRENCHES

Location	Sample*	Depth, cm	Total % sand
Near well 6	1	20-30	74
	2	90-120	87
	3	150-250	86
	4	210	81
Near well 4	5	0-15	63
	6	30-75	82
	7	90-150	94
	8	210-240	100
245 m back along drain tile & ditch along gravel road	9	20-38	63
	10	60-75	27

* Samples 1-8 were from areas that caved in and samples 9-10 did not cave in.

The pond was designed by the Soil Conservation Service, USDA, and built by the Agricultural Research Center. It is approximately 0.4 hectare (1 acre) in area and 165 cm (5.5 feet) deep (3760 cubic meter (1 million gallon) capacity, equivalent to about 1 month's drainage.) A stand pipe outlet 30-cm (12-inches) in diameter and valved bottom drain 20-cm (8-inches) in diameter were installed to regulate the pond water level.

The two drain lines shown in Figure 1 drained directly into the pond. In addition a diversion terrace was built to direct surface runoff into the pond from the east side. Surface runoff from the west half of the plot area was intercepted along the access road and diverted into drain line "B" by means of a gravel sump. Hence, line"A" emptied only underground water into the pond, whereas line "B" also handled surface runoff.

Soil Characteristics

The entire region to the south and including much of the plot area consisted of sandy soils. Specific soil types in the plot areas, as determined from the Prince Georges County Soil Survey Report and by mechanical analyses, are given in Table 3. The sandy soils in plots Ia-IVa (Figure 9) were generally deeper than those in plots Ib-IVb which were underlain more closely by clay. The range in depths and texture present permitted trenching in soils of somewhat different characteristics. In general, infiltration rates of rainwater into these porous sandy soils were high and provided a rather severe test for movement of

Table 3. SOILS AND WATER TABLE IN PROPOSED PLOT AREAS

Plot					Soil analysis**					
Proposed treatment width x depth x edge to edge	Number	Depth to Groundwater	Depth to Clay	Soil type*	pH+	Total N++	Soil fractions*+ O.M.	Sand	Silt	Clay
cm		m	m			µg/g	%	%	%	%
Digested 60 x 60 x 60	I a	0.8-4.6	1.8-4.6	Mostly GeC a little KeB2	5.3	282	0.36	80	15	5
Digested 60 x 120 x 120	II a	1.8-4.6	3.4-5.2	GeC	5.2	318	0.39	74	18	8
Raw-limed 60 x 60 x 60	III a	0.8-1.4	1.5-1.8	GeC	5.0	323	0.55	77	15	8
Raw-limed liquid, 60 x 120 x 240	IV a	1.8-4.6	2.1-4.6	GeC	5.1	276	0.29	78	15	7
Control, 60 x 60 x 60	V a	0.6-2.1	0.9-2.1	GeC	5.4	334	0.62	81	13	6
Digested 60 x 60 x 60	I b	0.5-1.5	0.6-1.5	Mostly KeB2 a little GeC	5.6	379	0.69	79	15	6
Digested 60 x 120 x 120	II b	1.1-2.4	1.5-2.4	StB2	5.2	271	0.34	68	24	8
Raw-limed 60 x 60 x 60	III b	0.5-1.5	0.9-1.5	Partly StB2 partly KeB2	5.0	334	0.39	74	20	6
Raw-limed liquid, 60 x 120 x 240	IV b	1.1-1.5	1.2-1.5	Mostly StB2 a little KeB2	5.2	285	0.31	74	18	8

Continued

Table 3 (continued). SOILS AND WATER TABLE IN PROPOSED PLOT AREAS

Plot					Soil analysis **					
Proposed treatment width x depth x edge to edge	Number	Depth to Groundwater	Depth to Clay	Soil type*	pH +	Total N++	Soil fractions *+ O.M.	Sand	Silt	Clay
cm		m	m			µg/g	%	%	%	%
Control, 60 x 120 x 120	V b 1	2.4-4.6	3.7-5.5	GeC	5.2	316	0.46	75	16	9
Control, 60 x120 x 120	V b 2	1.5-2.4	1.8-2.4	StB2	5.4	210	0.27	72	18	10
Pond	-----	0.1-0.5	0.3-0.8	Ek						

* Soil type code from Soil Survey Manuel for Prince Georges County: GeC = Galestown - Evesboro sandy loam; KeB2 = Keyport find sandy loam; StB2 = Sunnyside fine sandy loam; Ek = Elkton silt loam.

** Sampled to depth trenches were to be dug.

\+ Analyses by USDA-ARS, Beltsville, Maryland.

++ Analyses by USDA-ARS, Beltsville, Maryland on dry weight basis.

*+ Analyses by USDA-ARS, Beltsville, Maryland, and USDA-SCS, Beltsville, Maryland.

pathogens and nitrogen into groundwater. The soils were moderately to strongly acidic. The soil in the pond area was an excellent fine-textured material for pond building with very low seepage.

Wells

All the wells in the immediate plot area were drilled, grouted and sampled in April before sludge incorporation.

Drilling--A drilling rig with 15-cm (6-inch) augers, operated by the Maryland Department of Natural Resources, was quite suitable for making borings and taking boring samples up to a depth of about 15 meters (50 feet). After drilling each well, a 5-cm (2-inch) diameter polyvinyl chloride (PVC schedule 40) plastic pipe was installed into the well. Each pipe was slotted at 7.5 cm (3-inch) intervals over a 150 cm (5 foot) distance at the bottom, and the bottom end capped. A diagram of a well in cross-section is shown in Figure 4.

Grouting

After drilling the wells and casings were covered with plastic until they were grouted. The grouting procedure was recommended by Elmer Jones, ARS, Beltsville, Maryland. It consisted briefly of mixing Type 3 Portland cement for 10 to 15 minutes in a mortar mixer using exactly 10 parts cement to 6 parts water. The cement was then screened through 0.6 cm (0.25 inch) hardware cloth into a large container which had a 3.2 cm (1.25 inch) clear plastic drain line in the bottom. The container, which was in a pick-up truck, was then driven to the different wells. The cement-water mixture flowed freely from the container and remained quite fluid (suitable for grouting) for several hours. Just prior to grouting, sand was packed around the plastic casing to grouting depth as given in Table 1. A funnel connected to a 3.2 cm (1.25 inch) pipe 240 cm (8 feet) long was inserted into the 15 cm (6 inch) bore hole on the outside of the 5 cm (2 inch) casing. The cement grout was then poured into the funnel through a 0.6 cm (0.25 inch) hardware cloth screen (Figure 5). By grouting in this manner, water samples were pulled from the entire water table through the sand around the casing. If water were to be sampled from a specific location in the water table, grouting was installed to nearly that depth with the casing open only at that depth. The cement grouting was used to prevent surface water from running down the outside of the casing. Except in well 22 the procedure was very successful in achieving its purpose. Well 22, with an unfavorable ratio between cement and water, was grouted too shallow, cracked and allowed surface water penetration as shown in Figure 6.

Sampling -- Water was sampled from the wells for chemical and biological analyses by a sampling system shown diagrammatically in Figure 7 and pictorially in Figure 8. The plastic-covered weight, tubing, glass T and cap (all 0.9 cm (0.38 inch)ID) were sterilized in an ethylene oxide chamber prior to being permanently placed in each well. Initially a

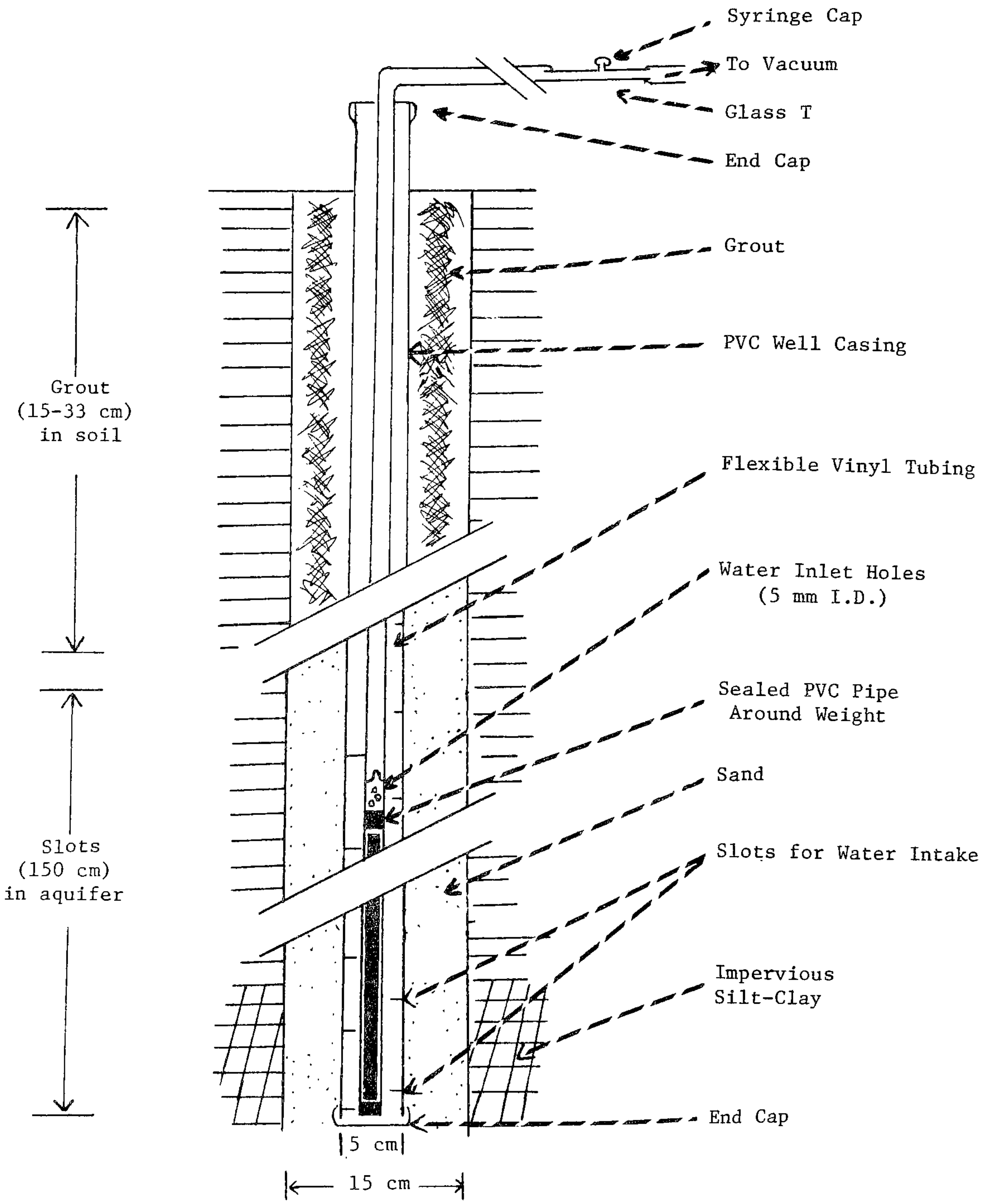


Figure 4. Well cross-section with water sampler.

Figure 5. Pouring cement grout around well casing.

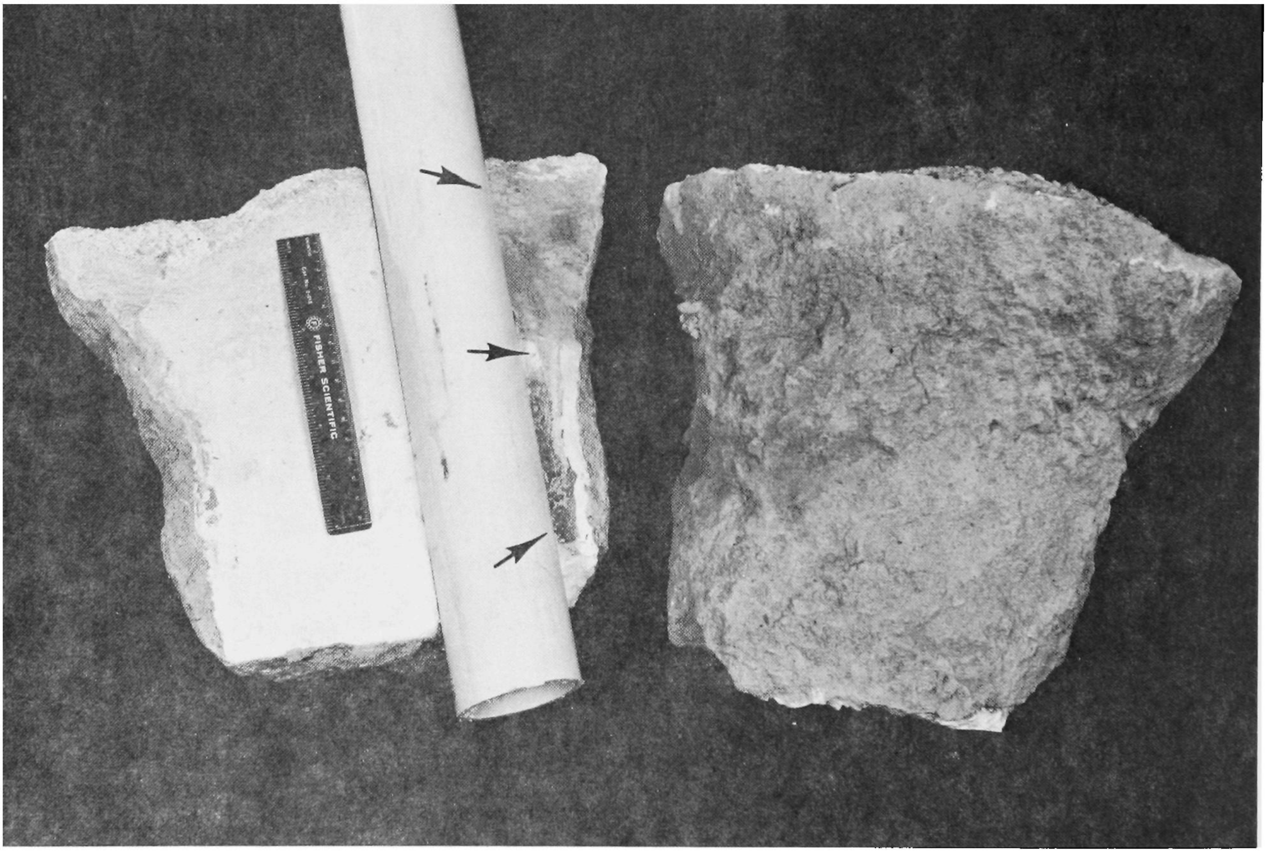


Figure 6. Grout failure on well 22.

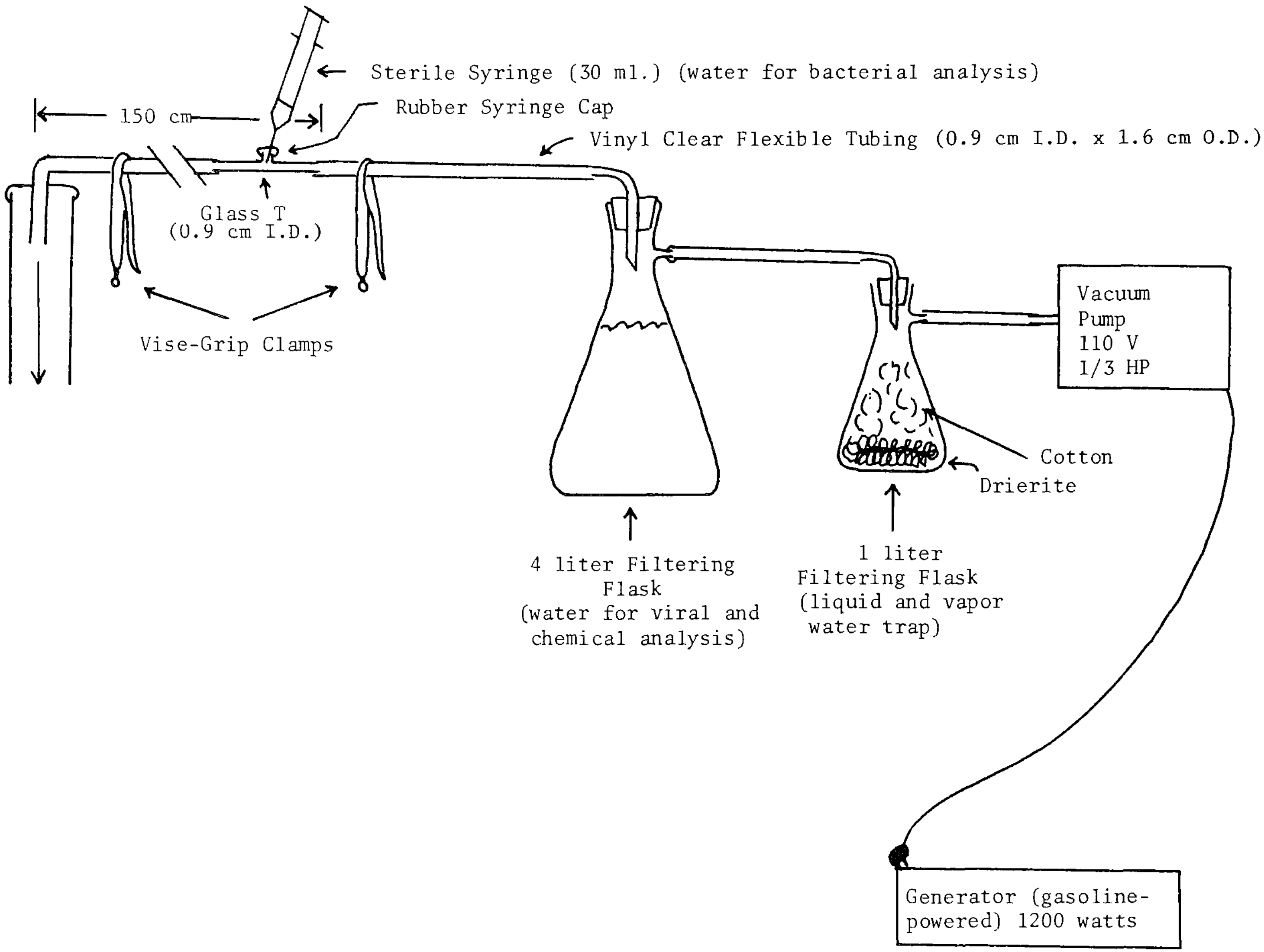


Figure 7. Water vacuum sampling system.

Figure 8. Well sampling.

volume of water was withdrawn from the well equal to that contained in the casing and then discarded. Then the tubing was clamped off below the glass T and a 90-ml water sample was withdrawn through a rubber serum bottle cap with a 30-ml disposable syringe and 18 gauge needle. For this purpose there were about 150 cm (5 feet) of tubing between the well cap and the glass T outside the well. The serum bottle cap surface had been sterilized with alcohol prior to insertion of the sterile syringe needle. The sample was collected into the syringes and ejected into a sterile bottle. This sample was saved for total coliform, fecal coliform, and in some cases salmonella analyses. For large samples for virus and chemical analyses the clamp was removed, suction reapplied, and a 4-liter filtering flask filled with sample water. These large samples were placed in 1.9- and 3.8-liter (1/2-and 1-gallon) plastic milk cartons, capped and refrigerated until analyses were made. A 7.5-cm (3-inch) casing, which would provide a larger volume of accumulated water and permit sampling by bailing as well as by vacuum, might prove more useful for future wells.

SLUDGE INCORPORATION

Two separate discussions of sludge entrenchment are included in this report. The first is written from an engineering viewpoint and the second from an agricultural and environmental research viewpoint.

Engineering Report by Whitman, Requardt and Associates (WR&A)

Introduction -- The Sludge Utilization Pilot Project performed at the Agricultural Research Center in Beltsville, Maryland, was conceived as a means of developing a safe and efficient manner for tilling sludge into the soil using standard items of equipment readily available on a rental basis. In addition, the project was planned to provide soil scientists at the U.S. Department of Agriculture Plant Industry Station an opportunity to compare the effect upon crop production of the treatment of a sandy soil with a variety of sludges applied at various dosage rates. The prime effort was directed toward simulating as nearly as possible the full-scale full-time operation at Cheltenham, Maryland, planned for the interim treatment period at the Blue Plains Plant.

Site Preparation and Maintenance -- Before beginning actual operation, the plots were laid out in the field. The layout permitted a comparison on a plot-to-plot basis of the operation of equipment in two slightly different types of soil. All of the entrenching studies were performed in each type of soil by dividing each of the plots into two parts as shown in Figure 9. The field layout was selected to provide adequate access to all plots and to shield, as much as possible, the sampling wells from the expected traffic flow pattern. Two access roads to the plots were constructed with bank run gravel, and a road was prepared to provide for one-way traffic around the field site. A terrace, which ran through all of the plots, was leveled to facilitate the operation of the equipment.

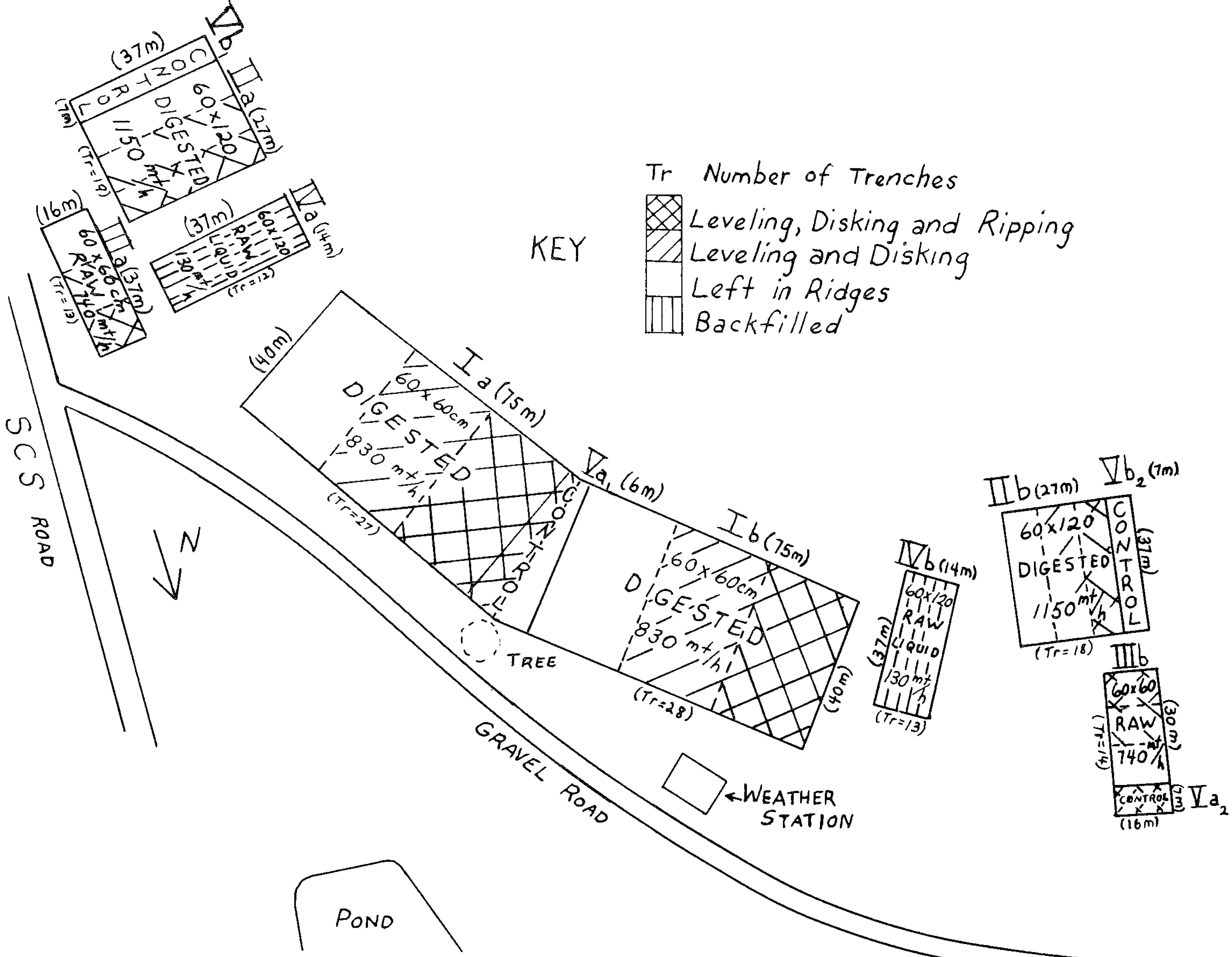


Figure 9. Plot dimension and tillage.

During the course of the project, the main one-way route was graded as much as possible to allow free flow of traffic. However, excessive amounts of rain and heavy traffic during the project at times made portions of the road impassible. The application of bank run gravel to the road provided only a temporary solution between rain showers. Finally, with the addition of a large amount of crusher run gravel (especially at low spots where trapped surface water made the base spongy), the road was reconstructed to better than its original condition.

Transportation -- Three different modes of transport were necessary because of the nature and variety of sludges in the pilot project and the physical restrictions of the outloading facilities at the various plants producing these sludges.

The digested sludge filter cake was hauled from Blue Plains in tandem wheeled dump trucks at a rate of approximately 12.5 cubic meters (16.5 cubic yards) per load. The total quantity transported in this manner was about 3200 cubic meters (4200 cubic yards).

The initial plan called for the trucks to drive directly onto the plots and discharge their contents onto the ground adjacent to the trench. Front-end loaders then gathered up the material and placed it in the trench. This approach immediately proved unsatisfactory because the trucks, forced to drive through the sludge on the ground, picked up sludge on their tires. In order to minimize the amount of sludge carried onto the highway, the trucks were routed along 915 meters (3000 feet) of earth road before returning to the main thoroughfare. The front-end loaders also had to maneuver through the sludge on the ground, and due to the slippery nature of the material, the operation of equipment was difficult and frequently was interrupted. The portion of the plot serving as access to the trenches finally became covered with a layer of sludge making movement nearly impossible. Indeed, the top layer of sludge-impregnated soil had to be removed in order to allow efficient operation of the equipment.

As a result of these difficulties, it was decided to excavate a series of shallow rectangular storage bowls, so that sludge could be discharged into the bowls at the sides and the loaders could enter the bowl at the ends to transport the sludge to the trenches. This method was successful and was used throughout the remainder of the pilot operation, both for handling the digested sludge filter cake from Blue Plains and the raw sludge filter cake from Fairfax County.

The various raw-limed sludge filter cakes were transported to Beltsville from three water pollution control plants in Fairfax County, Virginia: the Little Hunting Creek Plant, the Dogue Creek Plant and the Lower Potomac Plant. The planned system for transport of raw-limed filter cake involved placing an 18-meter (20-yard) Dempster Dinosaur container at each of the three plants to collect the sludge and setting up a pick-up schedule in which full containers were delivered from each plant to the field site and replaced with empty containers from the site. The

Little Hunting Creek Plant and the Dogue Creek Plant, however, produced relatively small amounts of sludge. In addition, handling of the containers from the Dogue Creek Plant was difficult since the sludge was low in solids (15%) and overflowed the sides of the container when it was loaded onto the truck for hauling. Transport of sludge from three plants also created an intricate hauling schedule which the contractor, because of other commitments, was unable to meet. For these reasons, sludge was ultimately taken only from the Lower Potomac Plant. With transport from only one plant the container was left on the truck and the entire vehicle was positioned under a discharge chute for filling. Sludge from this chute tended to form mounds in the container. Despite frequent shifting of the container during filling, it was necessary to manually rake the sludge in the container for optimum use of its capacity. Upon arrival at the field site, sludge was discharged into shallow sludge bowls near the two plots designated to receive raw-limed filter cake.

The low rate of sludge production at the Fairfax County plants as compared with the time required for placing the sludge into the trenches, the lack of supervision during the filling of the containers (the units were not filled as much as they could have been), and the transport of sludge only in the evenings and on weekends produced a very inefficient operation. Arrival of the sludge at the site during periods of non-operation increased storage times and contributed to an odor problem at the site.

Raw-limed liquid sludge was transported in 23 cubic meter (6,000 gallon) tank trucks which contained tank pressurization for pneumatic discharge. In the initial plan, the trucks were to drive to the edge of the receiving plot and with assistance of the pneumatic system, if required, discharge the sludge by gravity directly into the ends of the trenches. During operation at the first liquid sludge plot, the wet conditions at the site prevented driving the trucks directly to the plot. Hence, the trucks were positioned on the access road and approximately 90 meters (300 feet) of 15-cm (6-inch) aluminum irrigation pipe was used to transport the sludge pneumatically into the trenches. The length of the pipe, its large size, and an uphill pumping direction prevented efficient operation. There was excessive bypass of air through the pipe, and sludge was transported in slugs. The lengths of pipe sections also did not correspond to the trench spacing and frequent disassemblies and relocations of the pipe were necessary.

The second plot receiving the raw-limed liquid sludge was directly adjacent to the main access road. It was possible to position the truck at the end of the trenches and satisfactorily discharge the sludge by gravity into the trenches.

With the pilot experience, the method of transporting sludge recommended for the interim project at Cheltenham, Maryland, is the containerization concept. Sludge should be sealed in steel, water-tight containers, and transported to the tilling site on tractor-trailer flatbed trucks.

Operation -- (a) General -- The sludge placement operation at the pilot project was devised to test equipment and procedures on a controlled small scale basis for their applicability to large scale projects. A Final Site Plan, including a brief description of the test operations (treatments), is shown in Figures 1 and 9.

(b) Treatment I -- The plot for developing full-scale entrenchment procedures consisted of one 0.6 hectare (1.5 acre) approximately 150 meters (500 feet) long and 40 meters (130 feet) wide. The area received digested sludge filter cake of approximately 22% dry solids. These sludges were incorporated into trenches 60 cm (2 feet) wide, 60 cm (2 feet) deep, and 60 cm (2 feet) apart, edge to edge (60 x 60 x 60 cm). The plot was laid out on a slope having a grade of approximately 10% and the trenches followed the contours in the area. The soil on half of the plot was a sandy loam; and that on the other half was similar but included a small precentage of clay.

The operations were begun by first excavating an initial trench along the entire uphill edge of the plot. As digested sludge filter cake arrived from Blue Plains, it was stockpiled in four storage bowls strategically located around the plot. Two front-end loaders, a wheeled loader (3.4 cubic meters (4.5 cubic yards) bucket) and a tracked front-end loader (1.9 cubic meters (2.5 cubic yards) bucket) carried the sludge from the bowls and placed it into the initial trench. After half of the initial trench was filled, the trencher began to excavate a second trench parallel to the first trench, and discharged spoil over the sludge placed in the first trench. After sludge had been placed along the entire length of the first trench and the second trench had been excavated, sludge was placed in the second trench and the third trench was excavated. This procedure continued until the entire 0.6 hectare (1.5 acre) plot had been treated.

Since the front-end loaders had to drive into the bowls to remove the sludge, there was some sludge carried into the field by the equipment. The sludge on the field later caused slippery conditions, especially after rain. A portion of the plot became difficult to work after rain because an underlying impervious clay layer had trapped water near the surface. The frequent traffic of heavy equipment across this area produced a spongy surface after heavy rain which made travel through the area impossible. In addition, the breaking up of the soil all of the way down to the clay barrier caused caving of trenches excavated in this area. However, with careful equipment operation, the area was trenched and the work in Plot I was completed.

Based on an average specific weight of 1000 kg/cubic meter (1700 pounds/cubic yard), the estimated total volume of sludge placed in Plot I was 1770 cubic meters (2320 cubic yards). The estimated dosage in this plot was 650 metric tons of dry solids/hectare (290 tons/acre). The design dosage was 670 metric tons of dry solids/hectare (300 tons/acre). The deficit was caused by a wider trench spacing than that planned, but was minimized by some overfilling of the trenches. The loader bucket volumes were such that two placements had to be made with each bucket load, and difficulty in controlling the amount of sludge discharged caused the overfilling. Sludge also was tracked onto the plot from the storage bowl by the equipment.

There was a definite odor problem during the operation because of the open storage of sludge for a period of time prior to placement in the trenches and because of a lack of odor control provisions at the site. However, once the sludge had been placed into the trenches and covered, the treatment of the entire plot completed, and the storage bowls filled and covered, the odor diminished appreciably.

Two basic types of equipment were utilized in the entrenchment operation. A tracked off-set wheel type trencher excavated trenches and simultaneously back-filled the sludge placed in previously excavated adjacent trenches. The lateral position of the trenching wheel could be offset to allow the machine to operate close to another trench and the wheel could be rotated so that it could be kept in a vertical position for ground slopes up to 12% maximum grade. The unit was equipped with a spoil conveyor which could place the spoil up to 3 meters (10 feet) away. The particular trencher used in this project performed efficiently in dry weather, but with the absence of grouser bars on the track pads, became unstable in wet weather. The tracks offered no traction on muddy ground, and when the machine slipped sideways away from the trench, the trenching wheel became twisted in the trench and the machine had to be pulled free. Operation of the trencher in poorly drained areas of the plot was tedious, and the filling of certain short sections of trench had to be omitted.

It was necessary for the trencher operator to see the previous trench in order to use it as a guide for excavating a new trench. However, the trencher was constructed with the operator's seat only on one side. Hence, the previous trench could only be seen clearly when operating in one direction. For the short length of the trenches, trenching in one direction proved an efficient means of operation. Initially, it was planned to excavate with the trencher wheel perpendicular to grade. However, observation of actual operation indicated that it was easier for the trencher to tilt the wheel such that it was always vertical. Tilting of the wheel to the vertical eliminated excessive strains on the structure of the machine, but increased the tendency of the downhill side of the trench to collapse. The operation of the trencher in this plot was rarely slowed, except in wet weather or when a rock became jammed in the spoil conveyor and had to be removed by hand. The trencher operated at speeds up to 7.5 meters (25 feet)/minute in the dry sandy loam.

The front-end loaders, employed to place sludge into the trenches, worked well in dry weather. The wheeled loader was fast and maneuverable, while the tracked loader was slower and tended to tear up the surface of the ground when adequate space was not available for maneuvering. However, during wet weather the wheeled loader frequently lost traction. While the tracked model with good wet weather traction was able to maneuver out of bad situations, the maneuvering tended to tear up the surface of the ground, making further operation difficult or sometimes impossible. Nonetheless the tracked loader was much better suited for operation in wet weather.

(c) Treatment II - A second plot (Number II) consisted of two 0.1-hectare (0.25 acre) subplots, each approximately 27 meters (90 feet) wide and 37 meters (120 feet) long (check plot excluded Figure 9). Approximately 410 cubic meters (540 cubic yards) of digested sludge filter cake of 22% dry solids was applied in each subplot for an average dosage rate of 908 tons dry solids/hectare (405 tons/acre). The sludge was placed in trenches 60 cm (2 feet) wide, 120 cm (4 feet) deep and 120 cm (4 feet) apart, edge to edge (60 x 120 x 120 cm). When the contents of one 3.4 cubic meter bucket load were placed in the trench, the material filled the trench to the top, with about 10 cm overfill. An increase in trench volume of about 2% due to caving contributed to a total increase in sludge volume of approximately 10% over the anticipated level.

The plot development was basically the same as for Plot I. Each of the two subplots were worked separately since they were located on opposite ends of the site. The rate of operation of the trencher was considerably slower than in Plot I because of the increased depth of the trench and because there was some caving of the sandy trench walls during the operation. The force exerted on the side walls of the newly excavated trench by the weight of cover on top of sludge placed in trenches on the uphill side of the new trench contributed to the wall collapse. When approximately six trenches had been filled, the combined load of all of these trenches was transmitted through the plot to the earth barrier on the uphill side of the trench undergoing excavation. As earth was removed from the ground to make the trench, the side force on the uphill sandy barrier resulted in caving of the trench wall. When this occurred at the immediate point of trenching, it was necessary to stop the forward motion of the machine and remove the excess earth. However, when caving occurred after the trencher had passed, no remedy was possible. Caving-in at the machine produced an increase in the dosage while caving-in after the trencher had passed did not. Caving-in due to the uphill surface loading could be controlled by periodically skipping a trench and thereby creating a barrier strong enough to withstand the load forces. Alternatively, the trencher could be started on the down slope side of a site, providing the slope is not so steep that the trencher slips into the previously dug trench.

The test operation located in the sandy loam with clay experienced more severe wall collapse than in sandy soil alone. After the passage of the trencher through soil pockets with heavy clay concentration whose boundaries were close to the trench walls, the remainder of the clay pocket in the side wall of the trench fell away into the bottom of the trench.

(d) Treatment III - A third plot (Number III) was used to study the effects of emplacement of raw-limed sludge filter cake averaging about 20% dry solids into the soil. The plot consisted of two 0.05-hectare (0.12-acre) subplots, each approximately 37 meters x 14 meters (120 feet x 45 feet), located at opposite ends of the site. Approximately 190 cubic meters (250 cubic yards) of sludge were placed in each subplot, for an estimated dosage of 735 metric tons dry solids/hectare (320 tons/acre). The operation was identical to that used in Plot I. With the low sludge production of the Fairfax plants, the filling of these plots proceeded at a rate of one or two trenches at a time. The raw-limed sludge exhibited handling characteristics similar to the digested filter cake. It was again somewhat difficult to control the amount of sludge discharged from the front-end loader buckets and approximately 25% overfilling occurred.

(e) Treatment IV - A fourth (Number IV) plot consisted of two 0.05-hectare (0.12-acre) subplots with trenches 60 cm (2 feet) wide and 120 cm (4 feet) deep. The planned spacing of the trenches was 180 cm (6 feet) apart, edge to edge. The trenches were filled approximately one-half full with raw-limed liquid sludge (8% dry solids) delivered to the site from the Blue Plains plant in tank trucks. Since only one tank truck was available during the project, the rate of delivery of sludge to the site was too slow to allow the trencher to backfill a previously excavated trench immediately after sludge was discharged into it. Therefore, it was planned to excavate all the trenches in the plot in advance to avoid tying up the trencher for a long period of time. As the trenching of the first of the subplots proceeded, it was quickly learned that edge to edge spacing had to be increased to between 240 to 300 cm (8 to 10 feet).

The method used to fill the trenches has been described previously. The intended method for covering the trenches filled with liquid sludge was to begin at one edge of the plot and to push the spoil into the trench. During actual operation, a number of methods were tried. The crawler front-end loader attempted to push the spoil into and over the sludge. The motion of the soil along the ground surface caused the sides of the trenches to collapse, and sludge was forced out of the trench onto the ground. The second method employed the front-end loader to pick up the spoil and place it on top of the sludge. Along those portions of the trench which were narrow, this worked fairly well since the earth could bridge the distance between the trench walls and form a cover over the sludge. However, along those wider portions of the trench where caving had occurred during excavation, placement of soil on top of the sludge merely displaced the sludge, and again it overflowed the sides of the trench. The method which proved most satisfactory involved using a small tractor dozer equipped with a three-directional positioning blade. The dozer had sufficient space between its tracks to straddle the trench and was light enough so that it did not overburden the trench walls. In moving along the trench, the blade pushed soil from the stockpile on each side of the trench onto the sludge. There was very little displacement of the sludge to the surface since the trench was closed in a zipper-like fashion. The addition of soil from each side of the trench enhanced the possibility of the soil bridging over the sludge.

(f) Treatment V - The fifth plot (Number V) consisted of a total of 0.1 hectare (0.25 acre) of land subdivided into smaller sections and located strategically around the site. Sludge was not applied in this operation, and the trenches excavated were backfilled immediately. Approximately 0.05 hectare (0.12 acre) was positioned between the two halves of Plot I, and was worked as a part thereof. About 0.02 hectare (0.06 acre) was attached to each part of Plot II, and to one of the Plot III subplots. These plots were employed as controls and while they received no sludge, they did undergo the variety of tilling operations.

(g) Tilling - In order to compare various methods of tilling sludge into the soil, each of the subplots was subdivided into three sections, one for each of three tilling methods. One tilling method consisted of leaving the windrows that were created during the entrenching operation undisturbed. The second tilling method consisted of leveling the windrows with a large tractor dozer (270 Hp, 28,000kg (62,000 lbs)) approximately 1 week after the sludge had been placed in the trenches.

After 3 weeks the section of the plot was prepared for revegetation by drawing a disk harrow with 50-cm (20-inch) diameter blades with a crawler tractor dozer, both perpendicular to the trenches and later parallel to the trenches. The time between leveling and disking allowed stabilization of the sludge/soil mixture and development of a firm foundation for moving equipment over the area in any direction.

The third tilling method consisted of leveling the windrows and then drawing a pair of ripper shanks mounted on a larger crawler tractor (385 Hp, 37,000 kg (82,000 lbs)) perpendicular to the trenches. The shanks were spaced approximately 3 meters (10 feet) apart and penetrated into the ground a distance of about 1 meter (3 feet). While ripping provided some local mixing action and pulled some sludge to the surface, a thorough mixing of the sludge and the earth was not achieved by making a single pass with 3 meter spacing through the section of the plot. The barrier walls between the trenches, which would normally provide a foundation for equipment support, were sufficiently broken down by the ripping action to prohibit several passes through the section with all heavy equipment except the largest crawler tractor. Approximately 3 weeks after the ripping was completed the section was disked. This period of time again allowed sufficient time for the earth/sludge mixture to stabilize, and the smaller tractor was able to traverse the plot parallel to the trenches without difficulty.

Conclusions and Recommendations -- The procedure for applying sewage sludge to the soil demonstrated during the pilot project at Beltsville was successful. A wheel type offset trencher to backfill one trench while excavating a new one was efficient. The use of shallow bowls for temporary storage of sludge between the time of arrival from the treatment plant and the time of placement in the trenches provided a suitable stop-gap means of separating the sludge transport function from the sludge placement operation during the pilot operation. Front-end loaders can be employed to transport sludge in the field from the storage bowls into the trenches.

The overall operation at Beltsville worked best in dry weather. With the available equipment it was nearly impossible to run a smooth and efficient operation during periods of heavy rain. The principle equipment responsible for successful operation during dry weather, the wheeled front-end loader, was also the main cause for failure during wet weather. This machine had the speed and capacity to swiftly move the material about the site and place it in the trenches. However, on wet ground it lost traction and mired itself into the ground. The loader was able to extricate itself in most situations, but the required movement rendered the ground surface impassible. A tracked front-end loader was also used in the project, but this machine, while operable under wet conditions, did not have the required speed to keep up with the work.

An additional wet weather problem resulted from poor access to the temporary storage bowls. Further, the use of bank run gravel in the construction of secondary access roads was not suitable for support of heavy vehicles under wet weather conditions. The dump trucks used in transporting sludge to the site became bogged down once they left the main access road. Their extrication became a full-time effort, and the operation was forced to cease until the site had dried considerably.

All of the tracked equipment was stable on the wet ground, except that the trencher had no grouser bars on its track pads and exhibited some tendency to slip.

A final source of concern was the odor evident around the storage bowls, especially those in which digested sludge was placed. The odor problem intensified when the sludge was left uncovered for extended lengths of time, especially during the periods of work stoppage after rain.

Based on experience at the pilot project, the methods developed in the project were adequate for dry weather operation. In wet weather, while equipment with tracks were operable, the operation was considerably slower. For large scale all-weather operation such as that planned at Cheltenham, Maryland, (discussed in a WR&A report entitled "Sludge Utilization Project" of August 1972) it is recommended that the sludge entrenching operation approximate a closed system. To achieve a closed system the front-end loader/storage bowl system should be replaced with a specially designed vehicle capable of conveying sludge from a hopper directly into a trench, while moving parallel to the trench. The sludge should be transported to the site in sealed water-tight steel containers, and be transferred by crane into the hopper on the special vehicle. For all weather operation, the trencher should be fitted with grouser bars on its track pads.

All access roads must be constructed with crushed rock so that the containers can be transported directly to the tilling site under all weather conditions. The problem of odor should be minimized by maintaining a pH of 11.5 or above in the sludge. An emergency system for odor masking should also be available at the site. The use of the crane for handling containers should provide the necessary separation of field operation from over-the-road transport operations. In case of emergency, or when special equipment is not available, the same crane can be used in conjunction with the front-end loader/storage bowl system to discharge sludge from the containers into the bowls. A better system for hauling and entrenching sludge using standard equipment is described in a later section of this report.

ARS Observations on Sludge Incorporation

Plots were laid out during the last week of April and sludge incorporation began at the site on May 1. The final plot layout, with subsequent final tillage operation, is shown in Figure 9. Identification of the entrenchment treatments are given in Table 3.

Timing -- Equipment was trucked to the site on Monday, May 1, 1972, with WR&A coordinating the field site work of F. E. Gregory and Sons the principal contractor and transportation. The equipment used for sludge entrenchment included that shown in Figure 10. On May 2 operations began with treatment IIa being completed in about 6 hours, and treatments Ia, Ib, and IIIa, were initiated. On May 3 rain forced a halt to the operations indicating the unsuitability of the roads and equipment for all weather operations. Trenching operations were resumed May 5 and plots Ia and Ib were completed on May 8 for a total operating time of 27 hours. A wet area in plot Ib slowed operations considerably and work on other plots also occurred during that period. Plot IIb was begun and completed in 6 hours on May 6, 1972 and plot IIIa was completed. Plot IIIb was begun on May 6 and continued through to May 11 as the raw-limed sludge cake slowly arrived. With only one tank truck in operation the liquid sludge was put into plot IVa on May 10 and 11 and into plot IVb on May 12.

The time schedule for the arrival of trucks carrying sludge was excellent. Staking in the plot area with metal posts and flagged string helped traffic control and avoided damage to the groundwater wells.

Tillage After Sludge Incorporation -- The tillage treatments are shown in Figure 9. The tilled plots, the plot area, and the pond are shown in the aerial photograph (Figure 11). It was necessary to level the ridges with a dozer before disking and ripping and to backfill the trenches in the liquid plots IVa and IVb with a small John Deere dozer and multiposition blade. It was very difficult to perform any tillage operations on plot Ib because of the extremely wet conditions. The sandy soil in plot Ib was rather closely underlain with clay. These conditions, along with all the rain and traffic, caused the plots to become very unstable.

Figure 10. Sludge incorporation.

Figure 11. Aerial photo of site (May 19, 1972).

One month after sludge incroporation and disking it was possible to run a wheeled tractor perpendicularly across the trenches on all plots except Ib. Ripping was initially attempted with a D-8 dozer and a trailing ripper shank about 75 cm (2.5 feet) deep. This ripping method was unsuitable. A D-9 dozer with two 120 cm (4 foot) long hydraulically operated ripper shanks was satisfactory. The ripping was done at right angles to the trenches.

Disking was performed with a D-6 dozer pulling a 50-cm (20-inch) farm disk. The disking satisfactorily smoothed the field but did not bring sludge to the surface.

Incorporation Equipment and Facilities -- (a) General - In spite of difficulties with rain and inexperience with the new type of tillage operations, the job was completed with standard equipment.

(b) Roads - If trucks enter the field site, roads must be stabilized with gravel or crushed stone or rain will make the roads difficult to use. During the pilot project over 25 mm (1 inch) of rain fell on the second day of operations and another 25 mm fell before operations were complete. Road maintenance required many loads of bank run gravel and crushed stone. Also required was the constant use of a road grader, the D-8 dozer, and the loaders for smoothing roadways and assisting mired equipment.

(c) Loaders - Under dry conditions the rubber tired C977 front-end loader was very satisfactory, being fast and nondestructive of sod. In the rain this machine lacked traction and was out-performed by a slower and smaller tracked loader although the latter badly tore up the sod. Both loaders spilled considerable amounts of sludge on the soil surface when moving it from the stockpiles to the trench.

(d) Trucks - The 12 cubic meter (16 cubic yard) dump trucks were not completely satisfactory for hauling sludge. About 10% of the sludge did not empty from the trucks, and some adhered to the tires and bodies during filling, hauling, and dumping. The sludge spilled along the highway, necessitating truck cleaning facilities at disposal fields. Sludge placement into pits from trucks proved most feasible for confining sludge while filling loaders.

(e) Recommendation for Road and Field Handling of Sludges - Because of the initial pilot experiences in hauling sludge in dump trucks and filling trenches with front-end loaders, a new system was proposed by WR&A in a report written for the Maryland Environmental Service in August 1972, entitled "Sludge Utilization Project." WR&A recommended hauling sludge in covered 10 cubic meter (12 cubic yard) containers that could be hauled on flat body trucks, tractor trailers, or by rail. These containers were to be emptied into a specially designed field hopper at the site. The 27.5 cubic meter (36 cubic yard) field hopper would be mounted on high flotation tires or tracks and be pulled with a tracked vehicle to the trenches where sludge could be augered and conveyed into the trenches.

Further experience revealed a considerably less expensive alternative. Sludge could be hauled in 12 cubic meter (16 cubic yard) concrete mixer type trucks as shown in Figure 12. In good weather these trucks pull into the field and discharge their sludge directly into the open trenches via their own extended discharge chutes. Alternatively, in dry weather or in wet weather, when the soil is incapable of bearing the load, the trucks can discharge the sludge into the hopper of a peristaltic pump which forces sludge through flexible and solid tubing into the trench. The solid tubing is attached to the front of a tracked vehicle that drives beside the open trench. The peristaltic pump system was proposed by Resources Management Associates for filling trenches with Blue Plains raw-limed sludge at a 36-hectare (90-acre) site in Montgomery County, Maryland.

(f) Trencher - The trencher was sufficiently versatile for trenching. It should have tracks with cleats to prevent slippage. The trencher is shown in Figure 13 digging a new 120-cm (4-foot) deep trench and simultaneously covering the previous trench now filled with sludge. Because of the wet ground and the spilled sludge the trencher slipped and caused uneven trenches. Furthermore, a dozer had to scrape off the surface occasionally to permit trencher operation. Two men worked with the trencher operator to help keep proper spacing between trenches and to keep them straight.

Trench Spacing and Sludge Application Rate -- (a) Spacing - The planned spacing between 60 cm (2 foot) and 120 cm (4 foot) deep trenches was 60 and 120 cm, respectively. The actual spacings were generally greater (Table 4). The wider spacing occurred in the large 60 cm deep trench test area (Ia and Ib) because wet soil caused trencher slippage down hill away from the previous trench. The spacing between 60 cm deep trenches in plots IIIa and IIIb averaged 60 cm as planned because the soil was nearly level or sloped slightly towards the area already trenched. The spacings in the 120 cm deep plots IIa and IIb were wider than planned for the reasons cited for plots Ia and Ib and because the very sandy soil caved in occasionally when trenches were 120 cm deep.

(b) Application Rates - Rate of application is dependent upon trench spacing, degree of fill with sludge, and sludge solids content. Digested sludge from the Blue Plains plant had been stockpiled for 2 or 3 months and hence its solids content was higher than the expected 20% (Table 4). As previously stated the spacing for digested sludge was wider than anticipated. Combining a greater sludge solids content and a wider spacing than anticipated with overfill of trenches resulted in the rates of application for digested sludge given in Table 4. Raw sludge application rates were as projected. Width between trenches was as predicted while sludge solids content was less and filling was greater than planned

Figure 12. Cement truck for hauling sludge.

Figure 13. Trencher

Table 4. SLUDGE ENTRENCHMENT DATA

Treatment a & b	Trench depth cm	Spacing between trenches* cm	Sludge type**	Solids %	Rate,+ dry metric tons/ha
I	60	90	Digested	27.6	830
II	120	150	Digested	27.6	1150
III	60	65	Raw-Limed	18.5	740
IV	120	260	Raw-Limed	9.3	130
V a	60	90	None	NA	0
b	120	150	None	NA	0

* Spacing is edge to edge.

** Digested and liquid raw-limed from Blue Plains and dewatered raw-limed from Fairfax plants.

\+ Assuming 1.0 wet metric ton per cubic meter of wet sludge, trench 10% overfilled, and trench width of 60 cm.

Liquid Sludge Incorporation -- The procedure for incorporating liquid sludge in the soil was unsatisfactory. The spacing between trenches for liquid sludge application in plots IVa and IVb was larger than for sludge cake (Table 4), because all trenches had to be dug before any liquid sludge was applied (because of hauling problems and the desire not to backfill immediatelv). Backfilling was delayed in order to determine if dewatering would occur and whether more liquid sludge could be applied. Dewatering occurred only very slowly and little additional sludge could be added. In addition, the trench sides caved in because of all the liquid, the sandy soil texture, and machinery and spoil burden forces.

Based upon the field experience with liquid sludge, the 120 cm deep trenches should be filled to not more than 1/3 to 1/2 full and then immediately backfilled as new trenches are dug. Spacing between trenches depends upon the ability of the soil between the trenches to withstand the hydraulic pressure of the liquid sludge and the other forces.

Odor -- Some odor problems occurred during incorporation of the aged digested sludge. There should be less problem with odor when incorporating freshly dewatered sludges by the clean system recommended in the previous section. Liming also retarded odor in the raw sludge. Odors rapidly subsided when sludges were entrenched. Very strong, objectionable odors occurred after placement when the raw-limed plots were disked. The odor persisted, however, only for 1 or 2 days.

Sludge Characteristics -- Approximately 25 out of the 250 truckloads of digested sludge were sampled for analyses. The digested sludges ranged in solids content from 18 to 35% with most samples ranging from 25 to 29%. The pH ranged from 6.3 to 7.3.

Twenty-three of 36 loads of raw-limed sludge from Fairfax, Virginia, were also sampled. The solids content of three loads sampled from the Dogue Creek Plant ranged from 12 to 14% solids and the pH varied from 11.6 to 12.0. The solids content of the sludge from the Little Hunting Creek Plant was 12.4% and the pH 11.4. The other 19 sampled loads were from the Lower Potomac Plant. Most of the Lower Potomac sludges had solids content ranging from 17 to 23%. Two loads were 34% solids. The pH of most Lower Potomac sludges ranged from 9.6 to 12.0. Three loads apparently did not receive lime treatment. Their pH was 6.2 to 6.6.

Sludges were composited and analyzed as shown in Table 5. These composited samples were sent to EPA in Cincinnati, Ohio for bacteriological and viral analyses. Liming very strikingly reduced the contents of coliform bacteria and other measured pathogens. The data shows that liming above a pH of 11.5 was necessary to markedly reduce levels of bacteria. Subsequent tests, however, indicated that salmonella and fecal coliform bacteria were apparently reproducing again as soon as the pH decreased with the conversion of $Ca(OH)_2$ to $CaCO_3$. Fecal coliform counts were fairly high in the unlimed digested sludge even though it had been stockpiled for 2 months or longer.

OTHER PROCEDURES

Planting

Early Summer 1972 -- After leveling and disking, the entrenchment plots were planted in early June with strips of two sweet corn varieties, two soybean varieties, and Kentucky-31 tall fescue (Figure 14.) Six species of fruit trees and 11 species of shade trees were also planted, mostly in the plots with ridges.

Fall 1972 -- Balbo rye was seeded in late October 1972 in the areas previously seeded to corn and soybeans. Several test strips of alfalfa were also planted (Figure 15).

Early Summer 1973 -- After the growth and harvest of rye, the areas were rototilled and fescue was seeded into the bulk of the plots where rye

Table 5. BACTERIAL* AND VIRAL** CONTENT+ OF COMPOSITED ENTRENCHED SLUDGES

Sample	Description	Total count++	Fecal coliform	Fecal streptococci	Salmonella species	Shigella*+	Virus**
1	Composited samples of Fairfax, Va., raw-limed sludge with low pH (below 11.5)+*	50,000/g	<30/g	5,000/g	<30/g	<30/g	negative
2	Composited samples of Fairfax, Va., raw-limed sludge with high pH (above 11.5)***	11,000/g	<10/g	<10/g	<30/g	<30/g	0.2/g
3	Liquid sludge, composited-Blue Plains, pH less than 11.5	6.7×10^{7}/100 ml	7,500/100 ml	44,000/100 ml	<30/100 ml	<30/100 ml	0.7/g
4	Liquid sludge, composited-Blue Plains, pH more than 11.5***	225,000/100 ml	<250/100 ml	<250/100 ml	<30/100 ml	<30/100 ml	0.7g
5	Composited samples of Blue Plains digested sludge hauled 5/2-3/72	2.56×10^{8}/g	23,000/g	39,000/g	>36/g	<30/g	negative
6	Composited samples of Blue Plains digested sludge hauled 5/5/72	3.6×10^{8}/g	7,500/g	8,000/g	>36/g	<30/g	1.0/g

Continued

Table 5 (continued). BACTERIAL* AND VIRAL** CONTENT+ OF COMPOSITED ENTRENCHED SLUDGES

Sample	Description	Total count++	Fecal coliform	Fecal streptococci	Salmonella species	Shigella*+	Virus**
7	Composited samples of Blue Plains digested sludge hauled 5/6/72	4.0×10^8/g	14,000/g	27,000/g	>36/g	<30/g	negative
8	Composited samples of Blue Plains digested sludge hauled 5/8/72	2.5×10^8/g	62,000/g	16,000/g	>230/g	<30/g	negative

* Bacterial analyses by B. A. Kenner, EPANERC, Cincinnati, Ohio

** Viral analyses by the Virus Laboratory, EPA, NERC, Cincinnati, Ohio

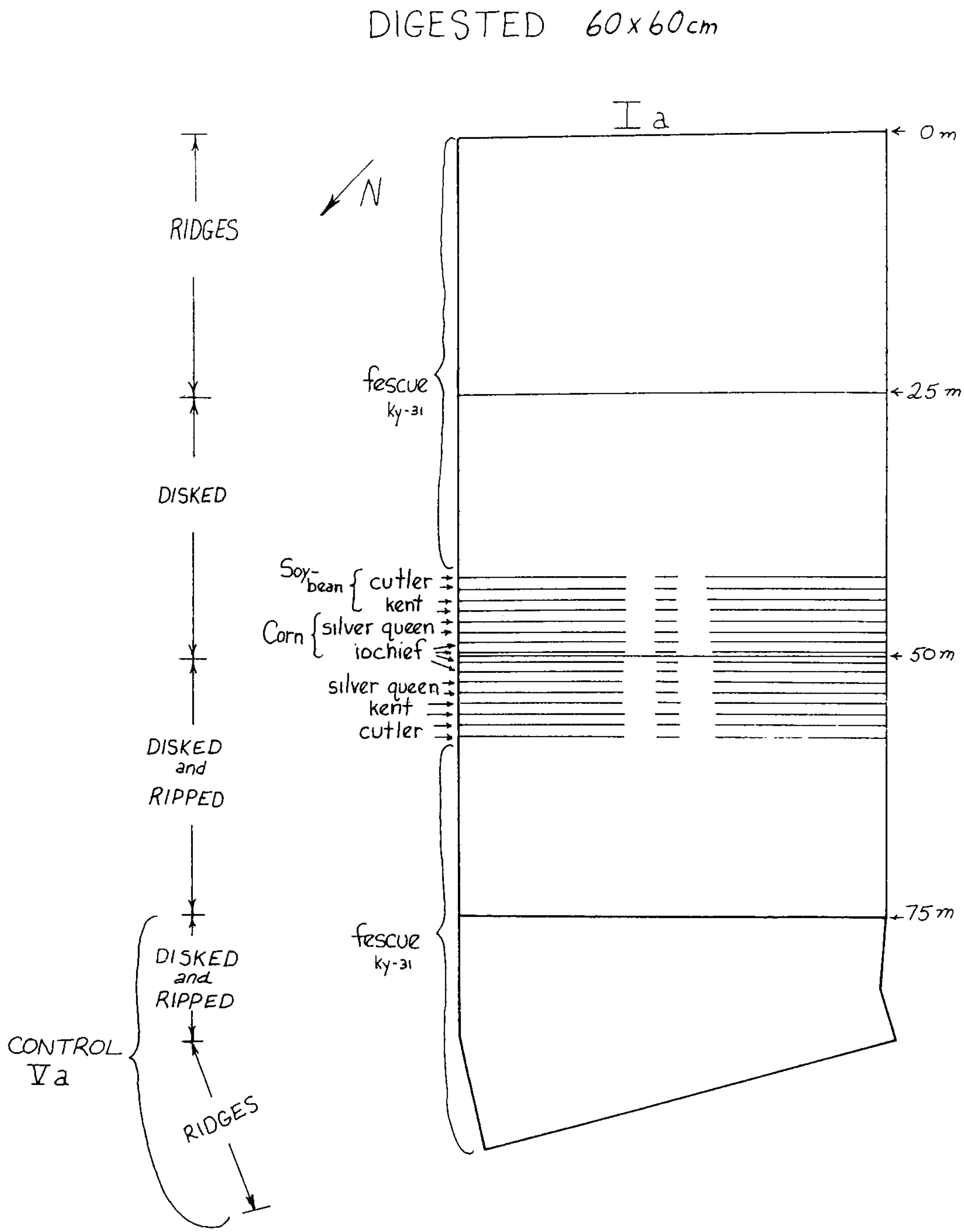
\+ All counts on a dry weight basis.

++ Total aerobic counts at 37°C for 48 hrs, samples 1, 5, and 7 had relatively low bacterial counts. The surviving bacteria were apparently spore-formers (*Bacillus sp.*). Numerous fungi also survived, mainly *Aspergillus sp.* and *Penicillium sp.* from their microscopic appearance.

*+ *Shigella sp.* - tests run by best available method and none were detected in any sludge samples.

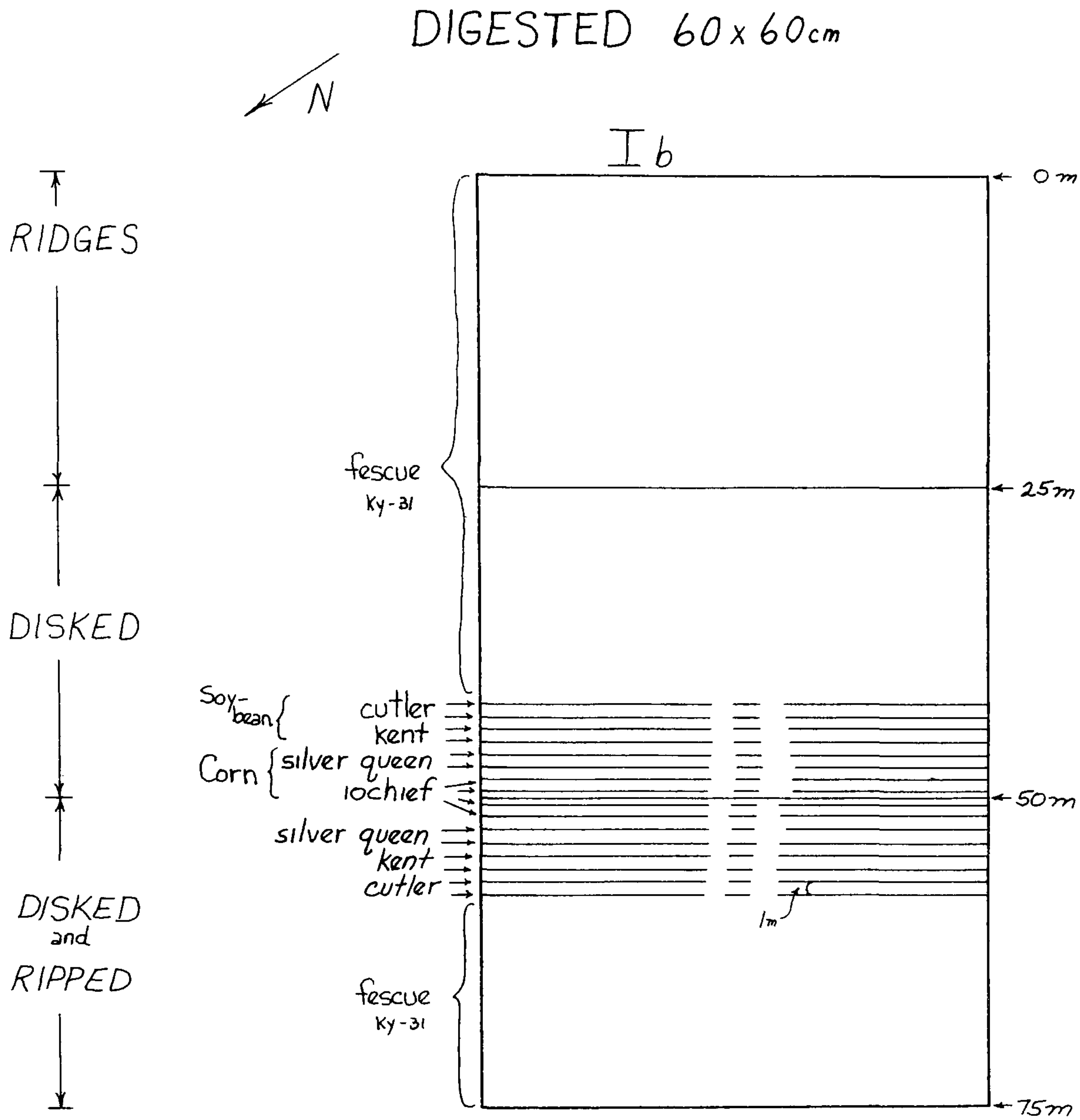
+* These pH determinations were made on refrigerated samples about 2 weeks after field delivery and some warming had occurred. This caused some reduction in pH from that determined on selected samples immediately after delivery. The fact that the pH was probably higher than when bacteria were determined likely accounts for the relatively low counts of bacteria in this composited raw-limed sludge.

*** Note the beneficial effect of liming to above pH 11.5



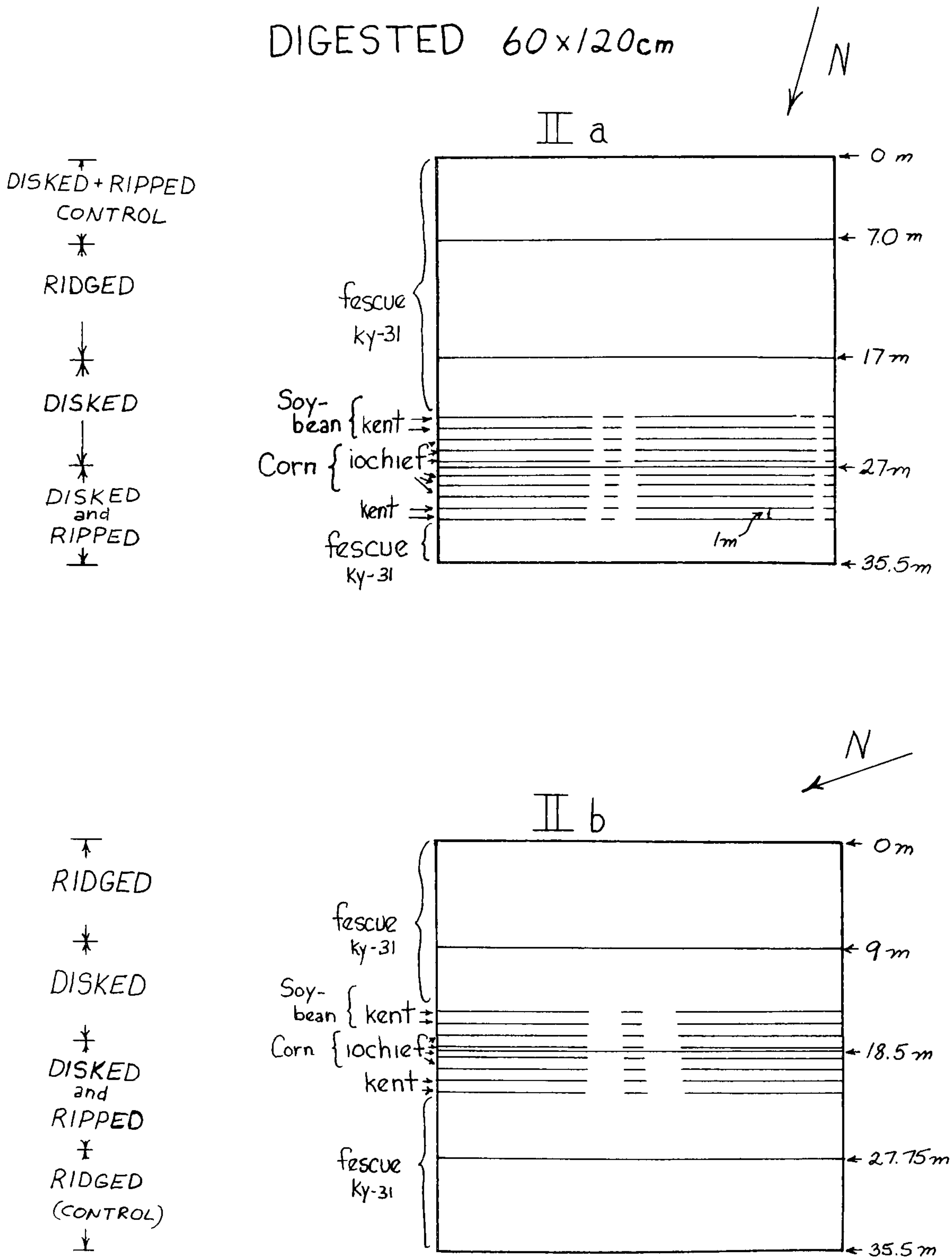
(A) Digested, Ia

Figure 14. Plot plan for crops planted in June 1972.



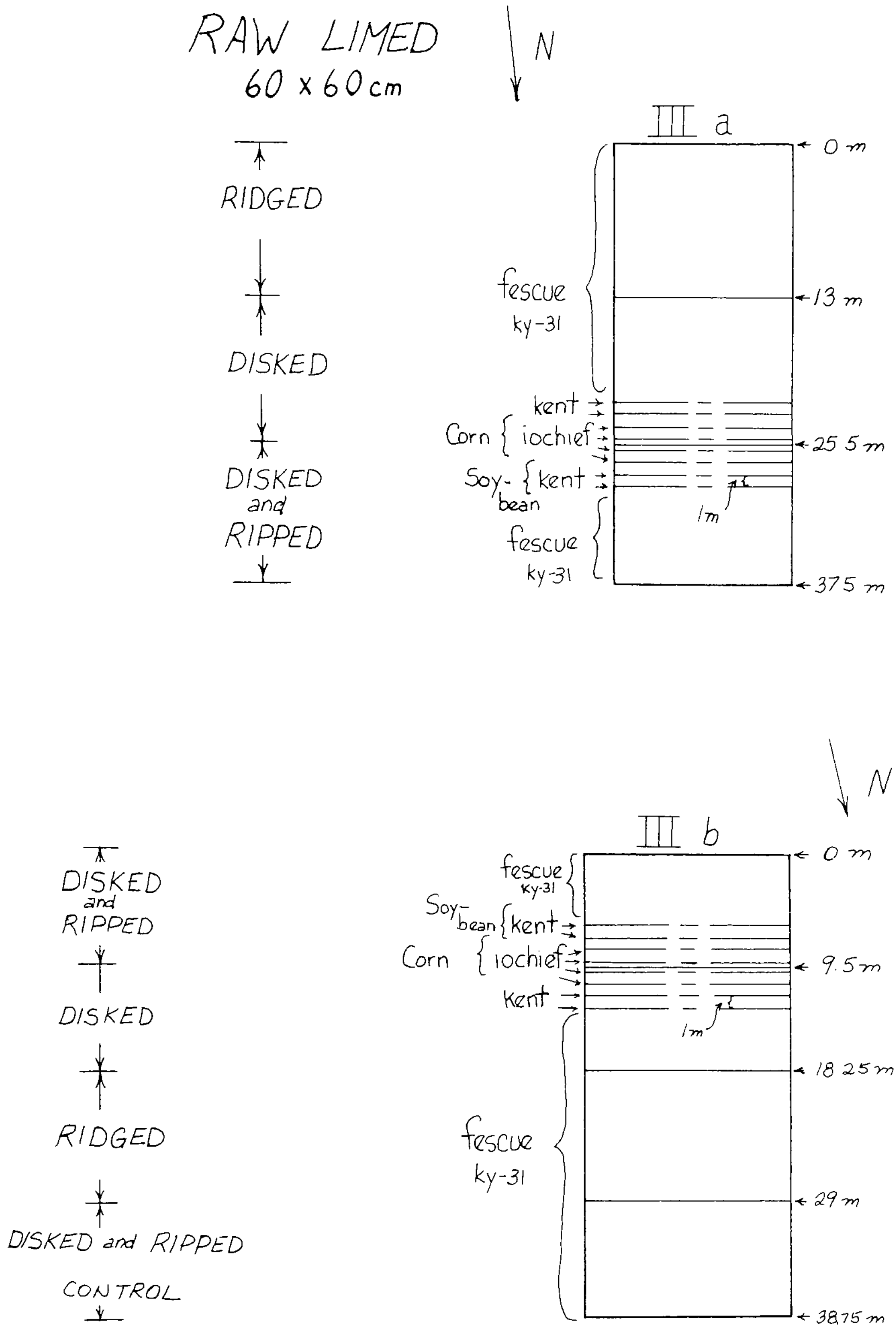
(B) Digested, Ib

Figure 14 (continued). Plot plan for crops planted in June 1972.



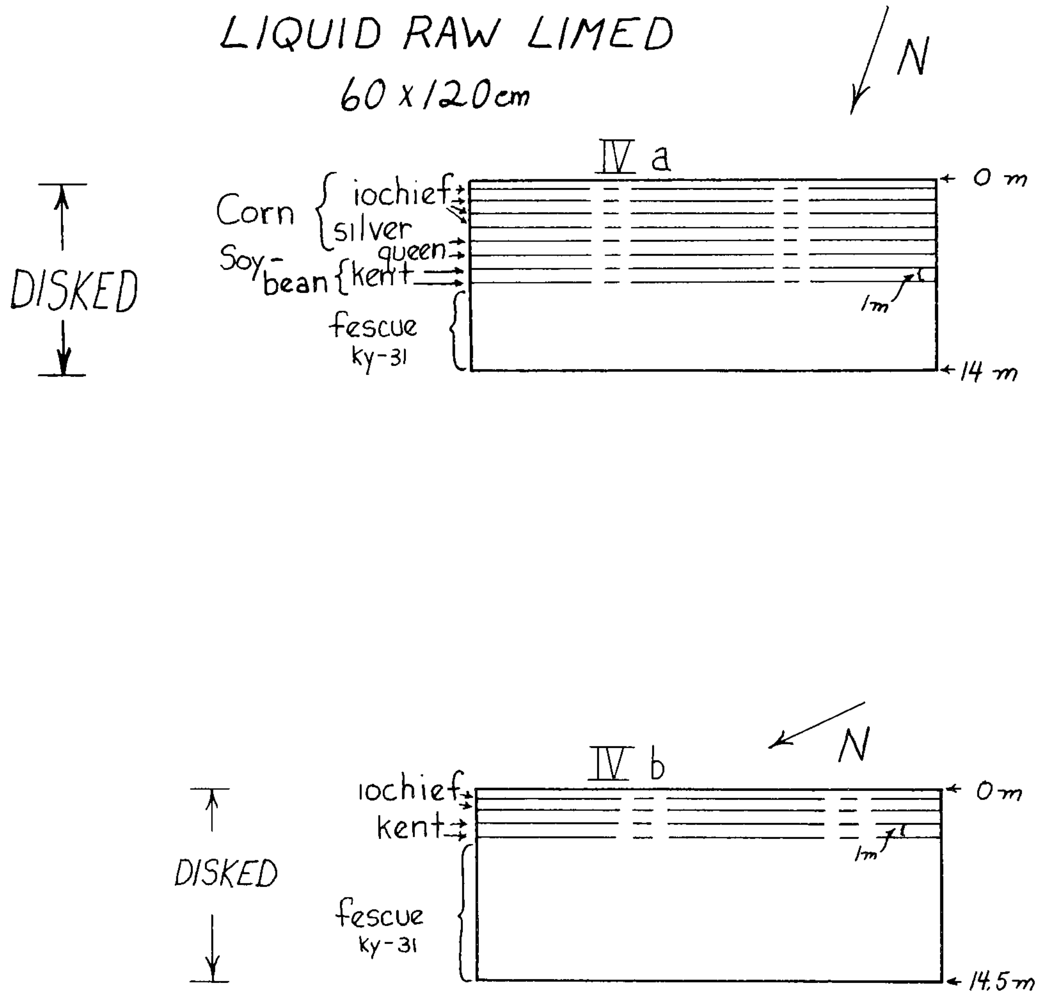
(C) Digested, IIa, IIb

Figure 14 (continued). Plot plan for crops planted in June 1972.



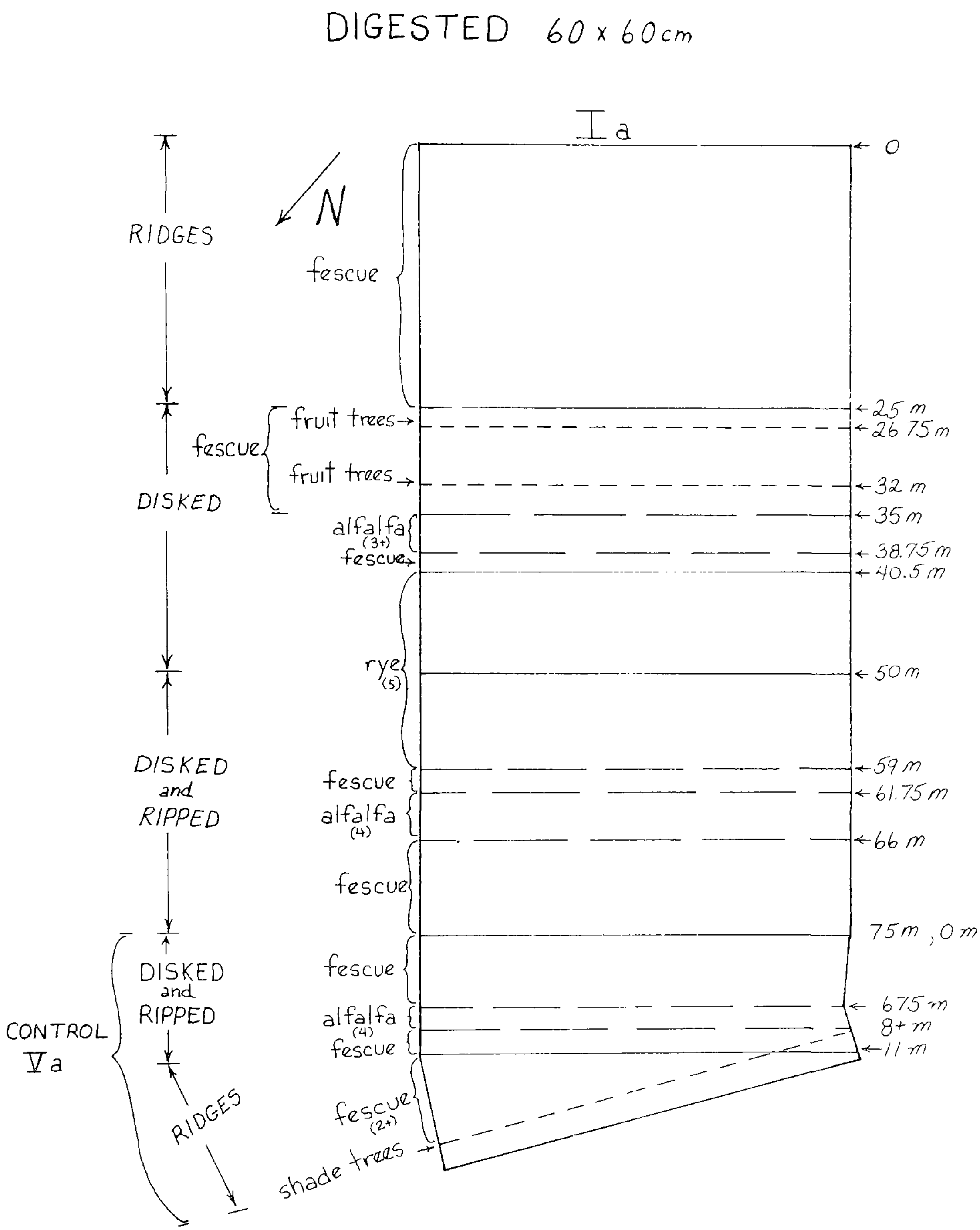
(D) Raw-limed, IIIa, IIIb.

Figure 14 (continued). Plot plan for crops planted in June 1972



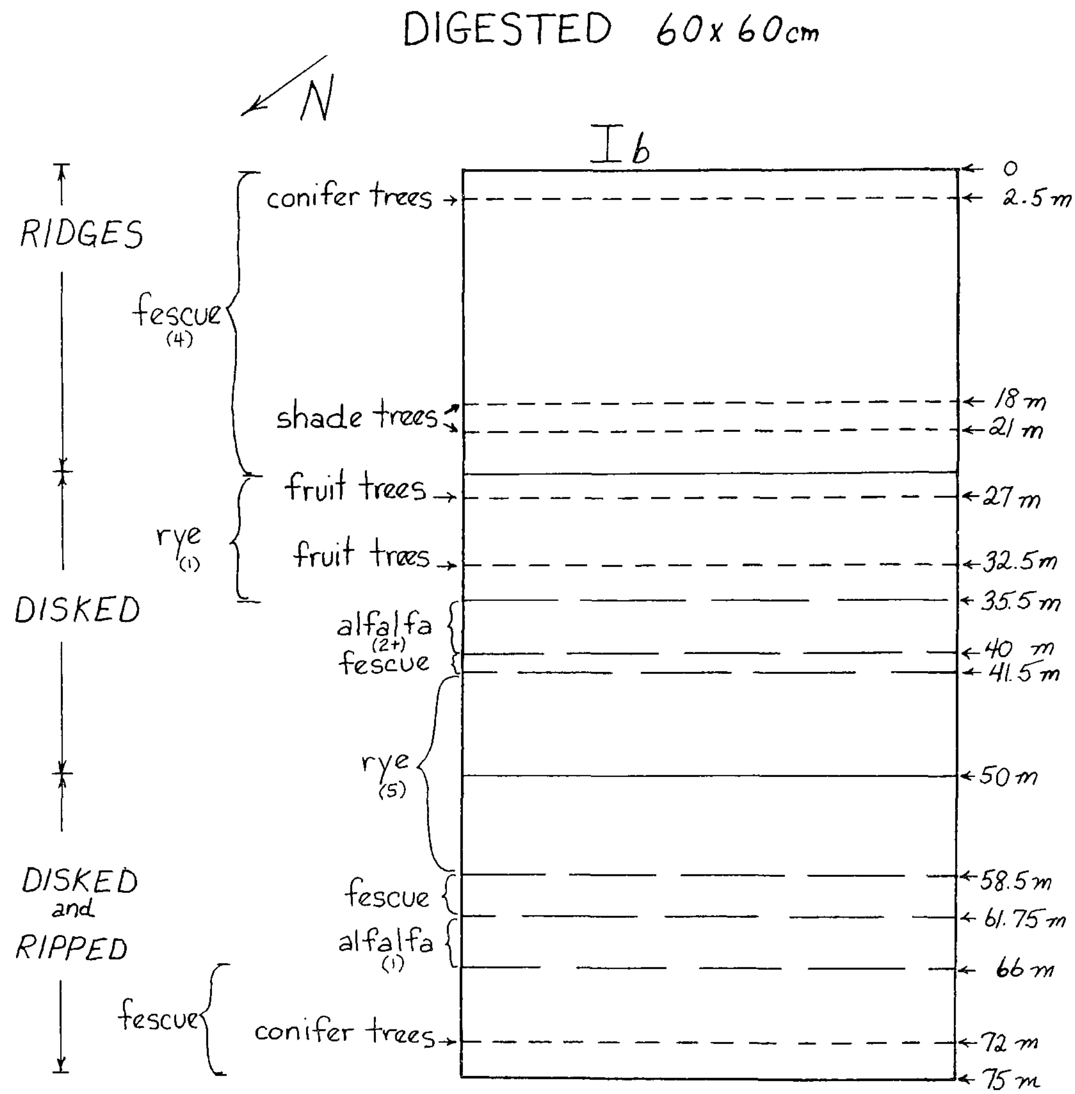
(E) Liquid raw-limed, IVa, IVb.

Figure 14 (continued). Plot plan for crops planted in June 1972



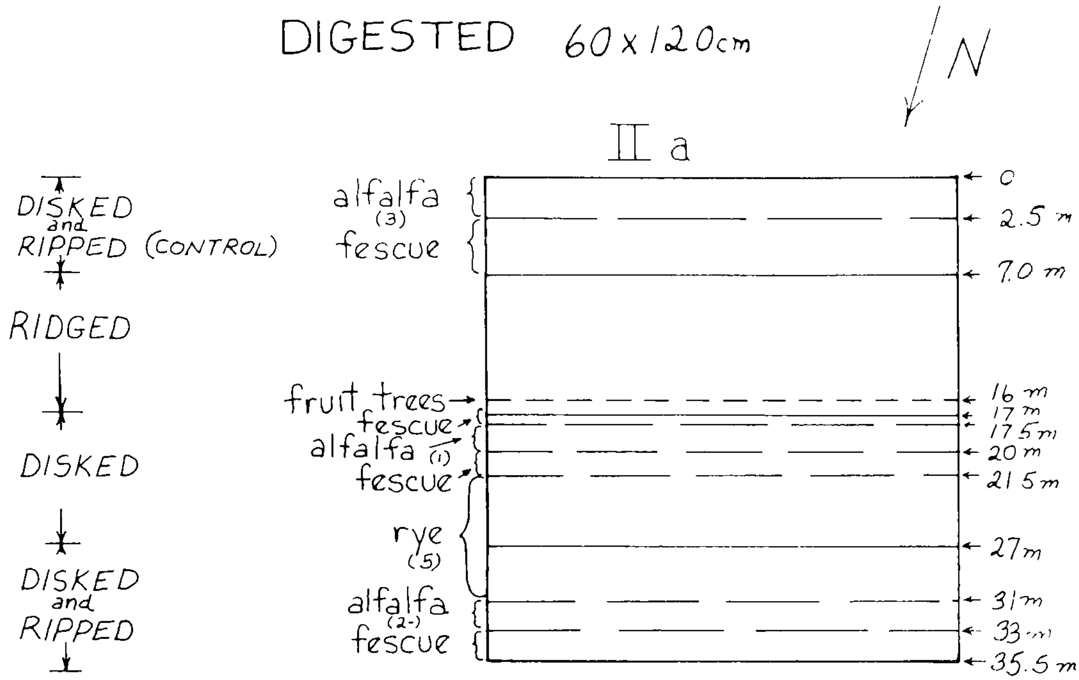
(A) Digested, Ia.

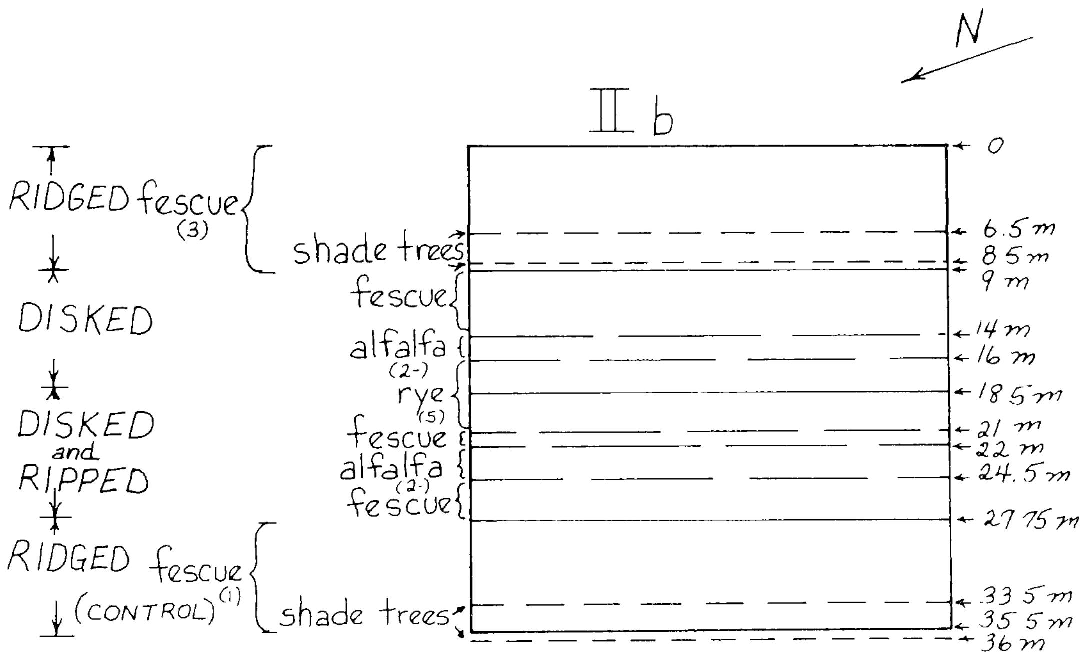
Figure 15. Plot plan for crops planted in October 1972 with crop stand ratings (1-poor to 5-very good) made on March 15, 1973.



(B) Digested, Ib.

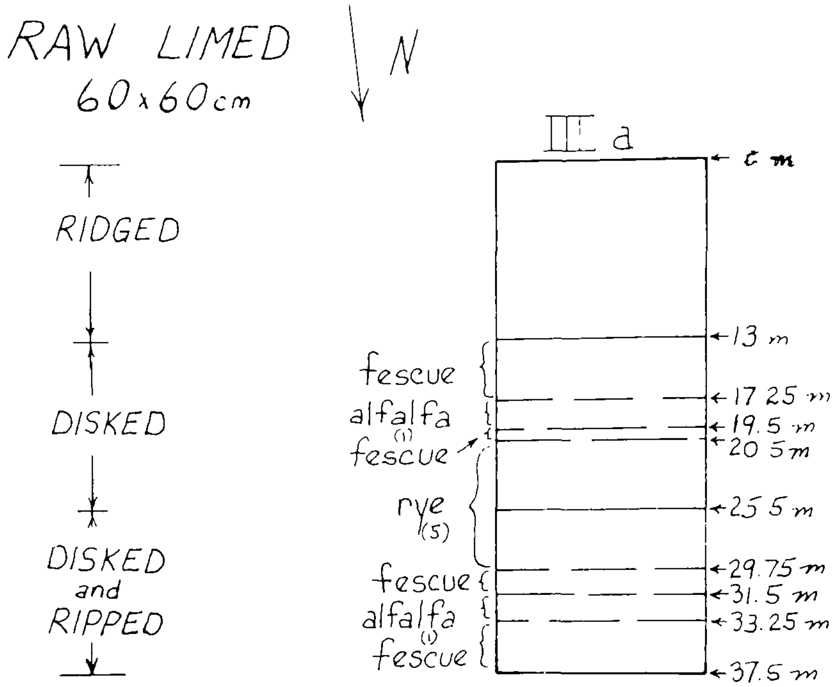
Figure 15 (continued). Plot plan for crops planted in October 1972 with crop stand ratings (1-poor to 5-very good) made on March 15, 1973

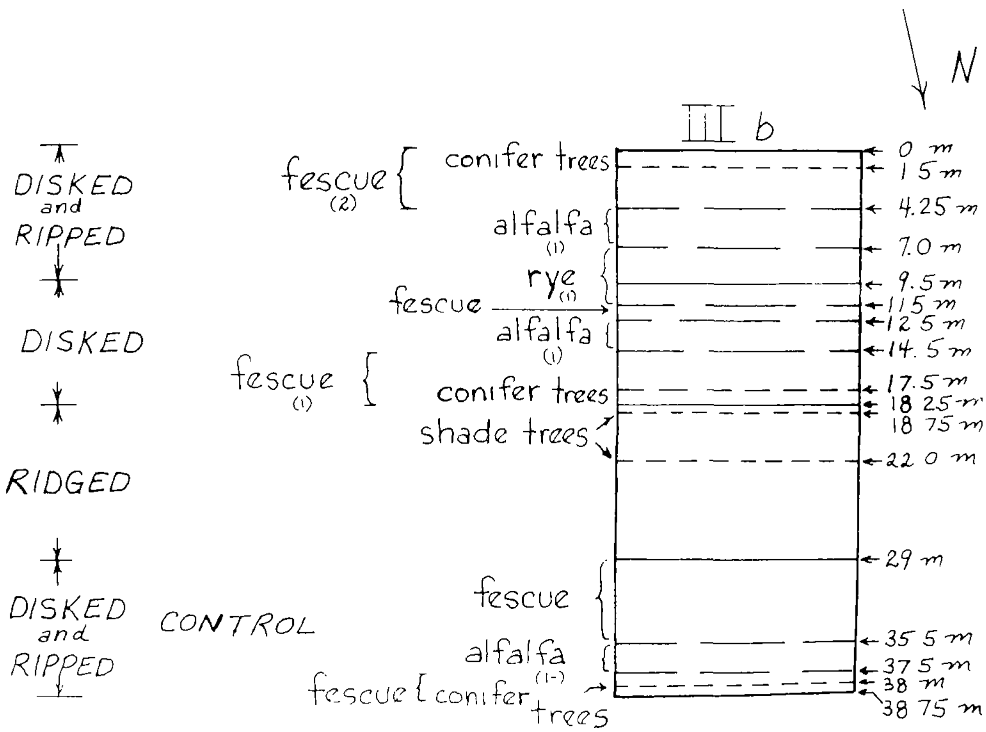




(C) Digested, IIa, IIb.

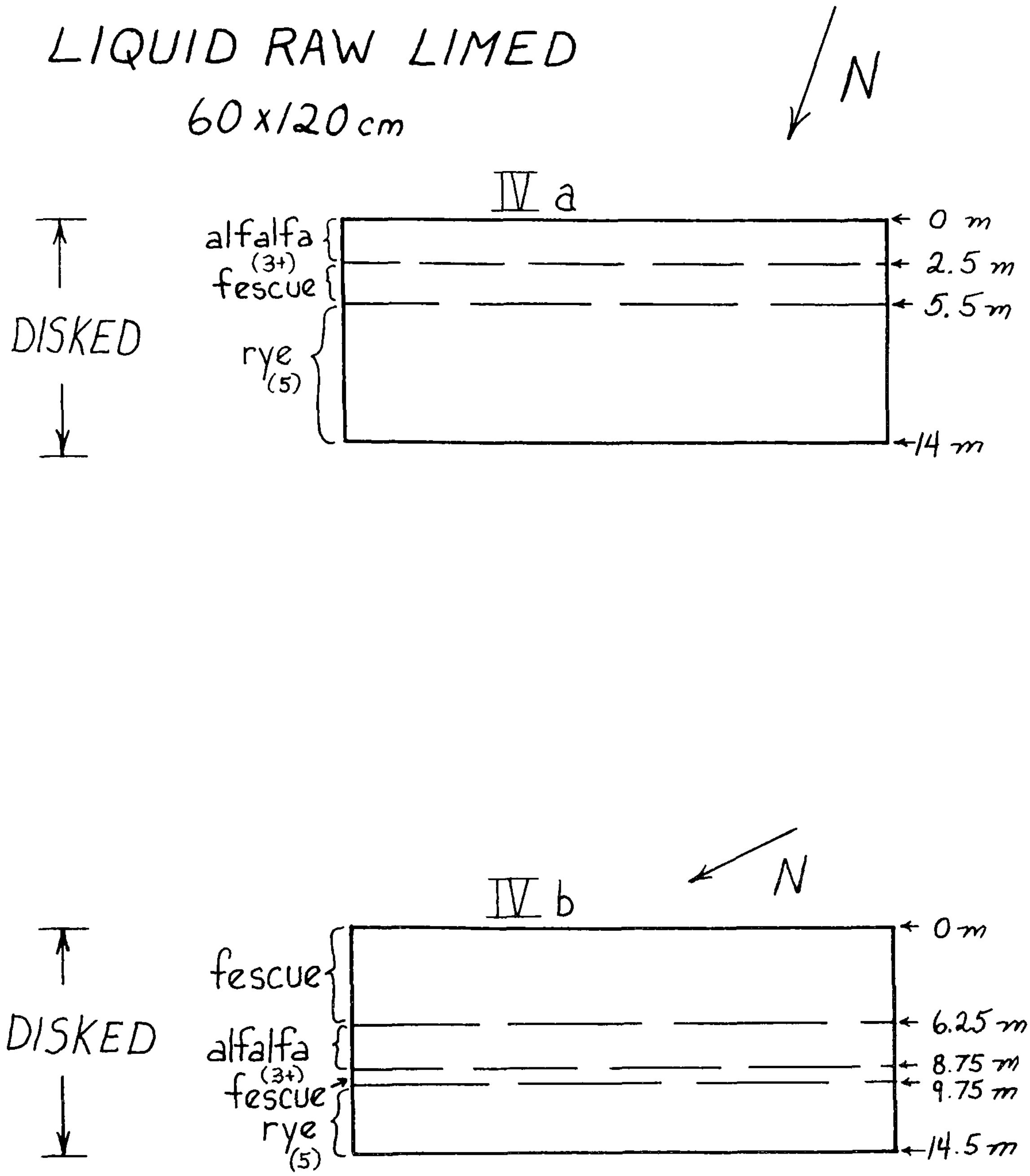
Figure 15 (continued). Plot plan for crops planted in October 1972 with crop stand ratings (1-poor to 5-very good) made on March 15, 1973.





(D) Raw-limed, IIIa, IIIb.

Figure 15 (continued). Plot plan for crops planted in October 1972 with crop standing ratings (1-poor to 5-very good) made on March 15, 1973.



(E) Liquid raw-limed, IVa, IVb.

Figure 15 (continued). Plot plan for crops planted in October 1972 with crop stand ratings (1-poor to 5-very good) made on March 15, 1973.

had been growing. Many shade and fruit trees were replanted. Many died because they had been planted so late the previous season.

Fall 1973 -- Areas were newly seeded to fescue and/or alfalfa that previously had supported poor stands of alfalfa or fescue (Figure 16). Also, much of the area left in ridges was now flattened and reseeded Plots IVa and IVb were releveled before reseeding. Finally part of plot Ia and IIb were fertilized by a surface addition of digested sludge before reseeding. The digested sludge was spread by bulldozer on the soil surface at a rate of about 23 dry metric tons/hectare (10 dry tons/acre-about 1.2 cm (0.5 inch) deep) and rototilled into the top 15 cm (6 inches).

Seedbed Preparation

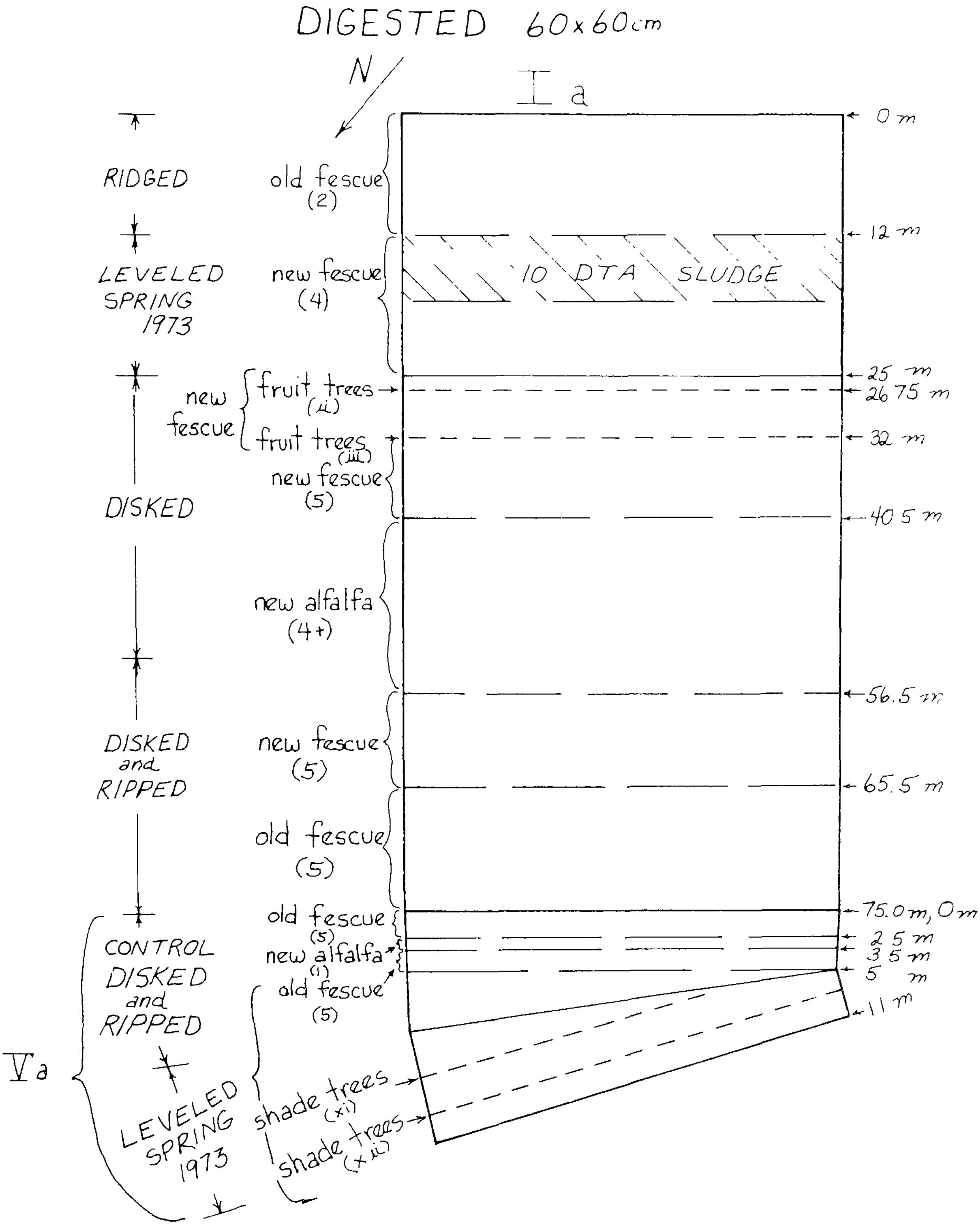
All plots received conventional tillage for seedbed preparation. Fertilizer and lime were needed for early growth of crops because of the infertility of the 30- to 37-cm (12- to 15-inch) layer of subsoil covering the sludge. Lime additions were at the rate of 3.4 metric tons/ hectare (1.5 tons/acre) of ground calcium limestone in 1972 and the same rate of ground dolomitic limestone in 1973. All plots received applications of 225 kg P_2O_5, 225 kg K_2O, and 35 kg N/hectare (200, 200, and 30 pounds/acre).

Most seeding was done with a tractor-mounted cyclone seeder. However, Kentucky-31 fescue was seeded in 1972 on the ridged plots using a hydroseeder (courtesy NASA, Buildings and Grounds) and on other plots by hand with a cyclone seeder. Subsequently fescue and alfalfa were planted with a tractor-mounted seed drill.

Plant, Sludge, and Soil Monitoring

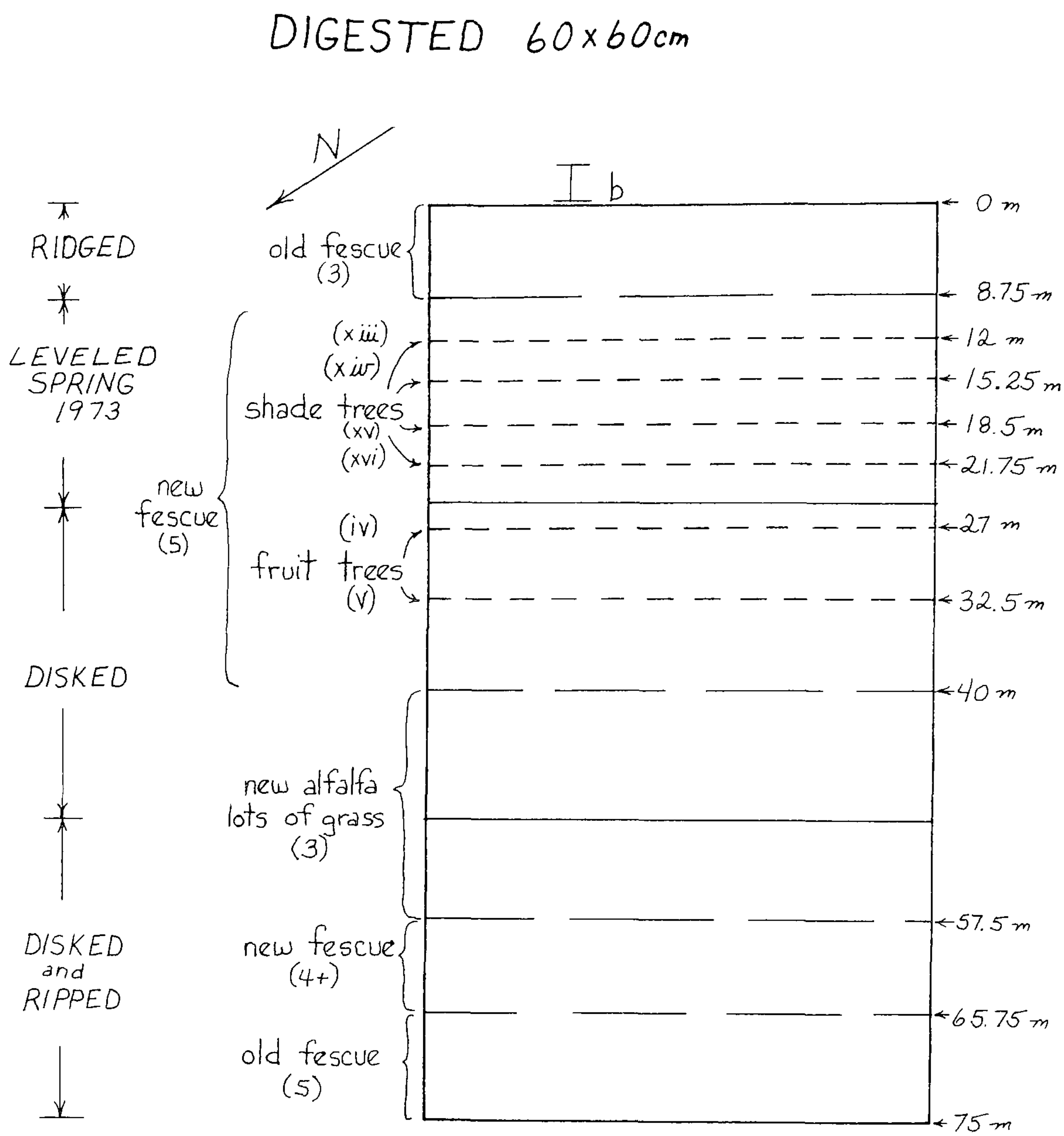
Gas Analysis -- Gas samplers (Figure 17) were installed at a number of locations in and around the entrenched sludges. The gas sampling system was developed by John Taylor, ARS. It consisted of a 10 cc disposable syringe with an on-off teflon valve and a 19-gauge needle. The gas was pulled into the syringe through a fine pore plastic tubing from a gas chamber placed in the soil or the sludge. The chamber was a 1.0 cm in diameter x 2.5 cm long piece of plexiglas tubing with a fine plastic screen (polyfilter GB) cover glued over the open end. Samples were taken periodically and analyzed with a gas chromatograph for O_2, CO_2, CH_4, and N_2.

Plant Elemental Analysis -- Samples of the different plant species were harvested periodically and saved for nutrient and heavy metal analyses. Plant nutrient contents were determined spectrographically by the Plant and Soil Analysis Laboratory in Athens, Georgia. Plant heavy metal contents were determined in our laboratories in Beltsville by Atomic Absorption Analysis using background correction after dry ashing up to 2 g of representative plant tissue overnight at 480°C, mixing with 20 ml of 1N HCl, and shaking occasionally over a 24-hour period.



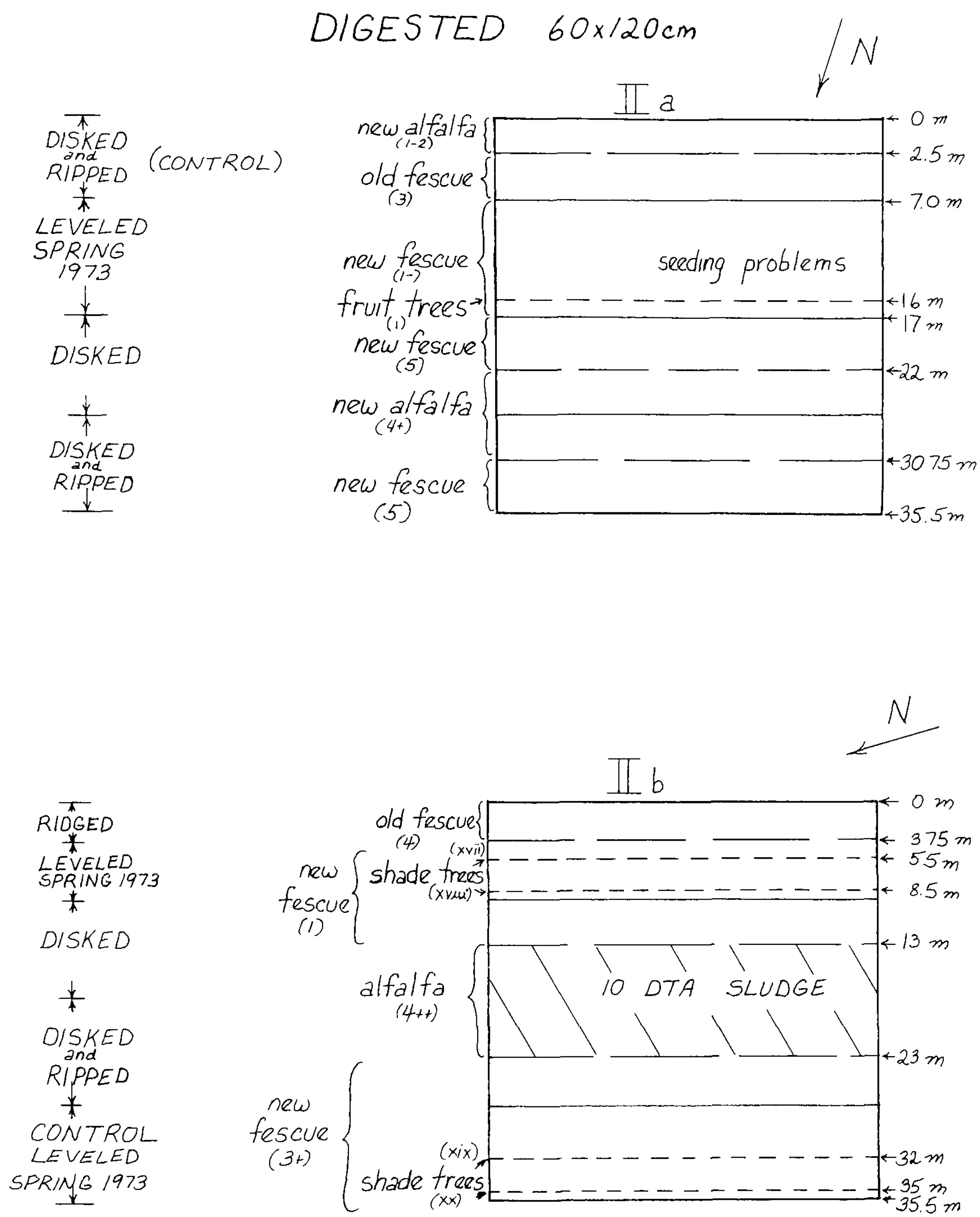
(A) Digested, Ia.

Figure 16. Plot plan for crops planted in early Fall 1973 with crop stand ratings (1-poor to 5-very good) made on December 4, 1973.



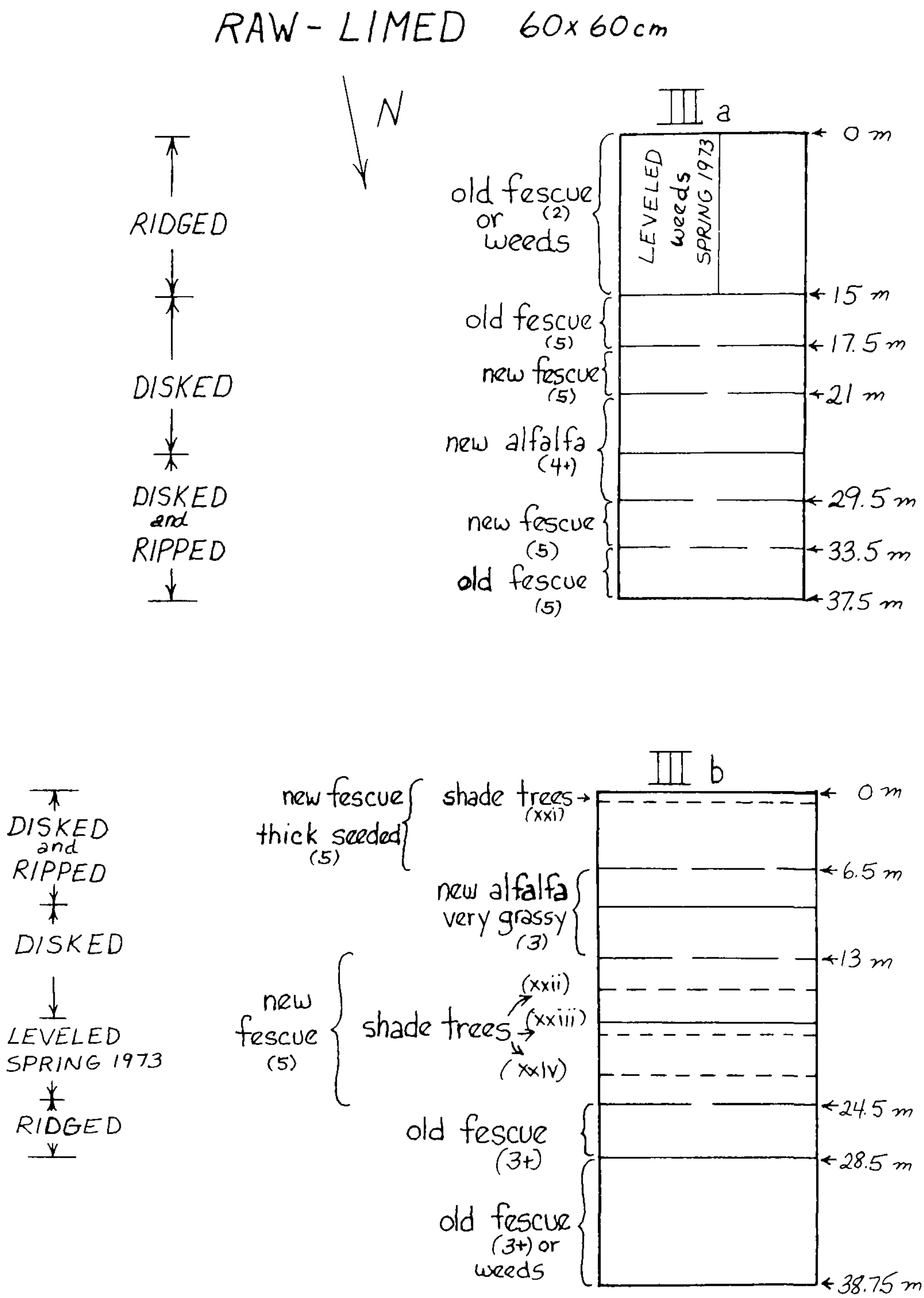
(B) Digested, Ib.

Figure 16 (continued). Plot plan for crops planted in early Fall 1973 with crop stand ratings (1-poor to 5-very good) made on December 4, 1973.



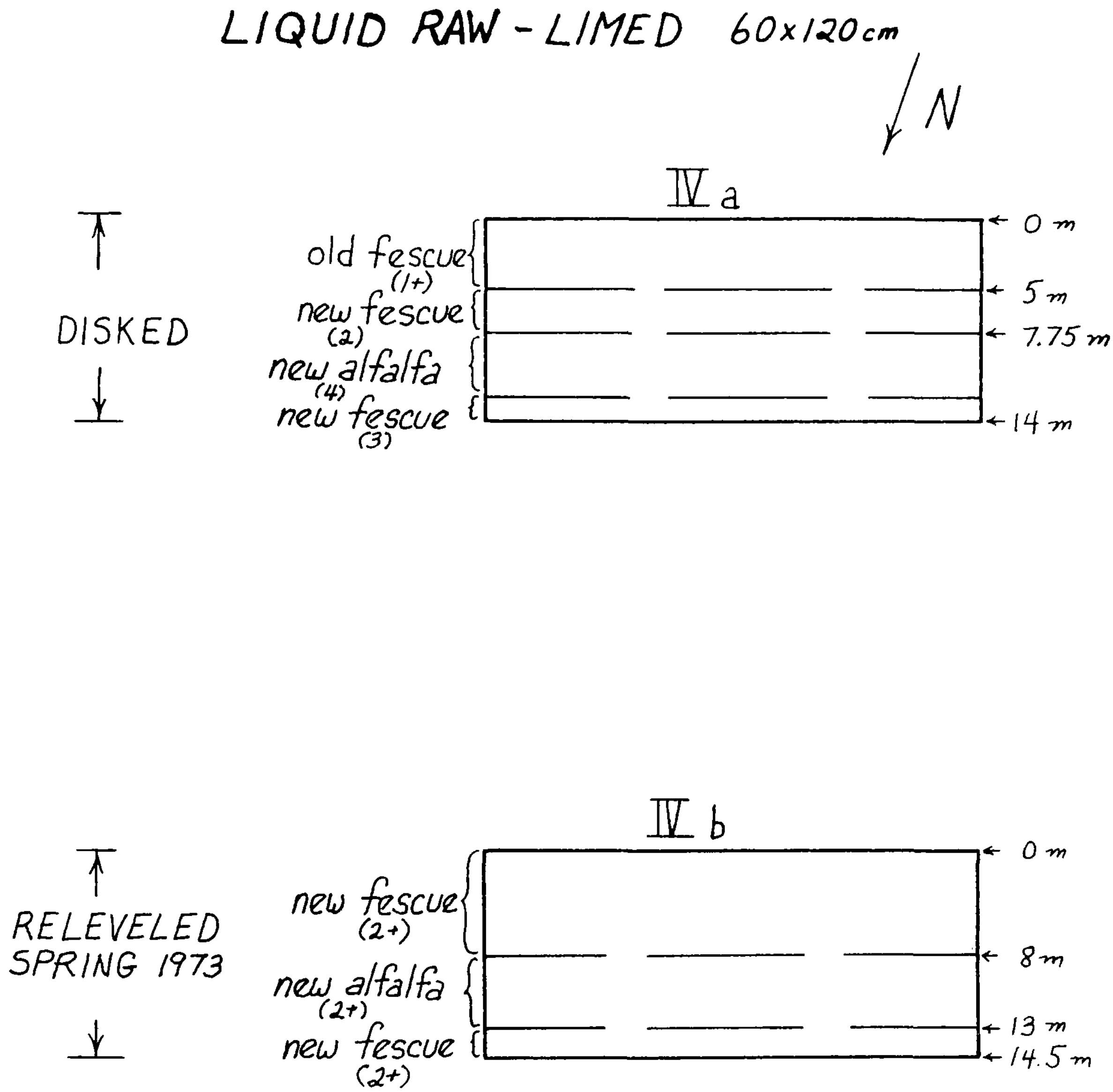
(C) Digested, IIa, IIb.

Figure 16 (continued). Plot plan for crops planted in early Fall 1973 with crop stand ratings (1-poor to 5-very good) made on December 4, 1973.



(D) Raw-limed, IIIa, IIIb.

Figure 16 (continued). Plot plan for crops planted in early Fall 1973 with crop stand ratings (1-poor to 5-very good) made on December 4, 1973.



(E) Liquid raw-limed, IVa, IVb.

Figure 16 (continued). Plot plan for crops planted in early Fall 1973 with crop stand ratings (1-poor to 5-very good) made on December 4, 1973.

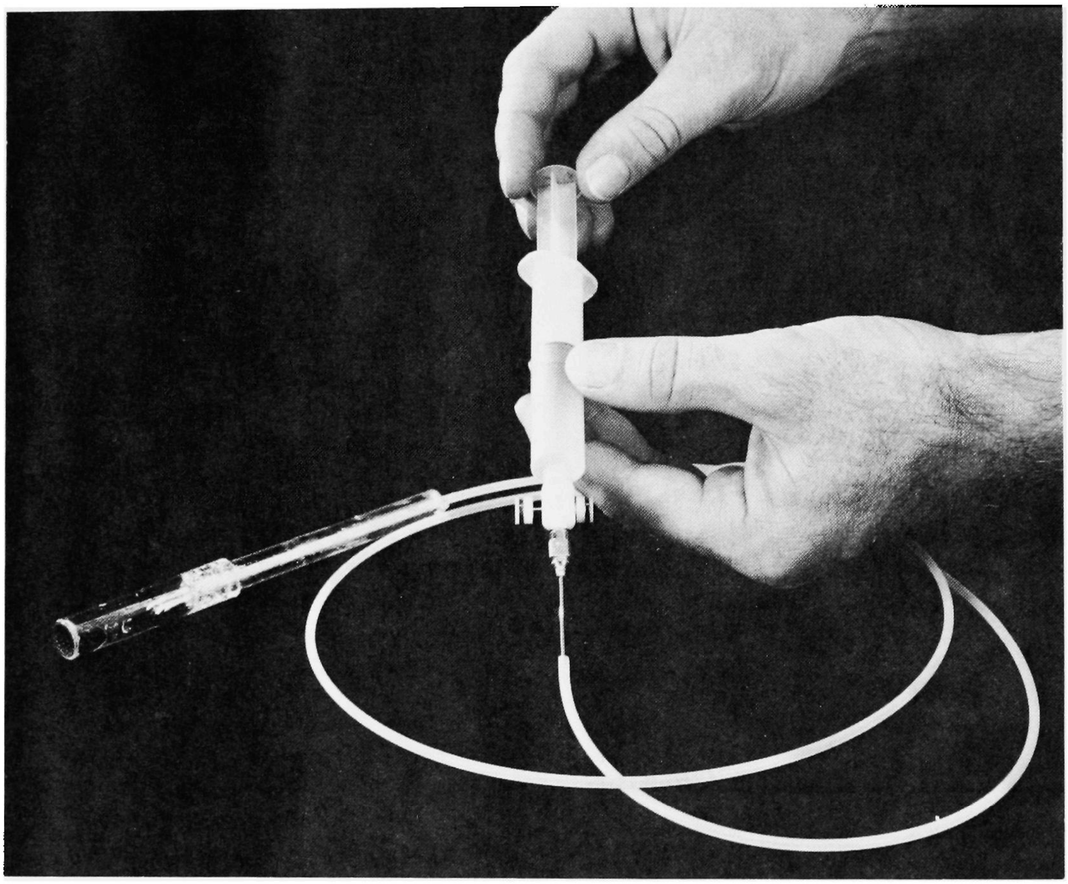


Figure 17. Gas sampling system.

Trenched Sludge and Surrounding Soil -- Observation trenches were periodically excavated at right angles to the trenches (Figure 18A). Detailed samples were taken from a grid around each trench (Figure 18B). Wooden tongue depressors were used to sample the soil and the sludge, and sterile whirlpak plastic bags were used to contain the samples. The samples were analyzed for total coliform, fecal coliform, and salmonella bacteria, forms of nitrogen, chloride, and less frequently for soluble carbon and heavy metals.

Salmonella and coliform analyses were conducted by our laboratories, by England Laboratories, by Woodard Laboratories, or by the Maryland Department of Health and Mental Hygiene. Total and fecal coliform bacteria were determined in test well water by the Most Probable Number (MPN) methods as described in the 13th edition of Standard Methods for Examination of Water and Wastewater, APHA, AWWA, and WPCF. For determination of these organisms and salmonellae in soil, sludge, and soil-sludge mixtures, approximately 50 g of sample were diluted 1:2 with sterile distilled water and shaken for 15 minutes at 250 excursions per minute. A serial 10-fold dilution was made from the suspension.

Fecal and total coliforms were determined in the dilutions by the above standard procedure. Salmonellae were determined by the MPN technique using the 10^{-1} to 10^{-4} dilutions. Three MPN tetrathionate broth tubes were inoculated for each dilution. After incubation at 35 to 37°C, a loop from each tetrathionate broth tube was streaked onto Brilliant Green Sulfa agar or Bismuth Sulfite agar plates. After incubation for 18 to 24 hours at 35 to 37°C, two to three suspect (pink) colonies were picked and inoculated onto triple sugar iron agar slants for incubation at 35 to 37°C for 18 hours. Cultures producing alkaline slants with acid butts were tested for agglutination with polyvalent O and polyvalent H antisera. Agglutination with both antisera were necessary as a positive test for salmonella bacteria.

Ammonium and nitrate nitrogen and chlorides were determined on 1N K_2SO_4 and 0.03N $Al_2(SO_4)_3$ extracts of soils and sludges (4 to 1) using specific nitrogen and chloride electrodes, and total nitrogen was determined by the Kjeldahl method in our laboratories. Total carbon was determined by the wet oxidation method and an index of soluble carbon was determined by running COD with the dichromate method on water extracts of the soils. Heavy metals were run on ashed samples of the sludge and on 1-20 extracts of sludges and 1-2 extracts of soils with 0.005M DTPA, 0.01M $CaCl_2$, and 0.10M TEA at pH 7.3 after Lindsey and Nowell.

Miscellaneous

Irrigation System -- A system for irrigating was assembled in 1972 which gave partial plot coverage. It was extended in 1973 for irrigating the entire plot area. The extended system consisted mainly of a Berkely pump Model B2EQL-30 with Wisconsin VH4D motor, 213 meters (700 feet) of

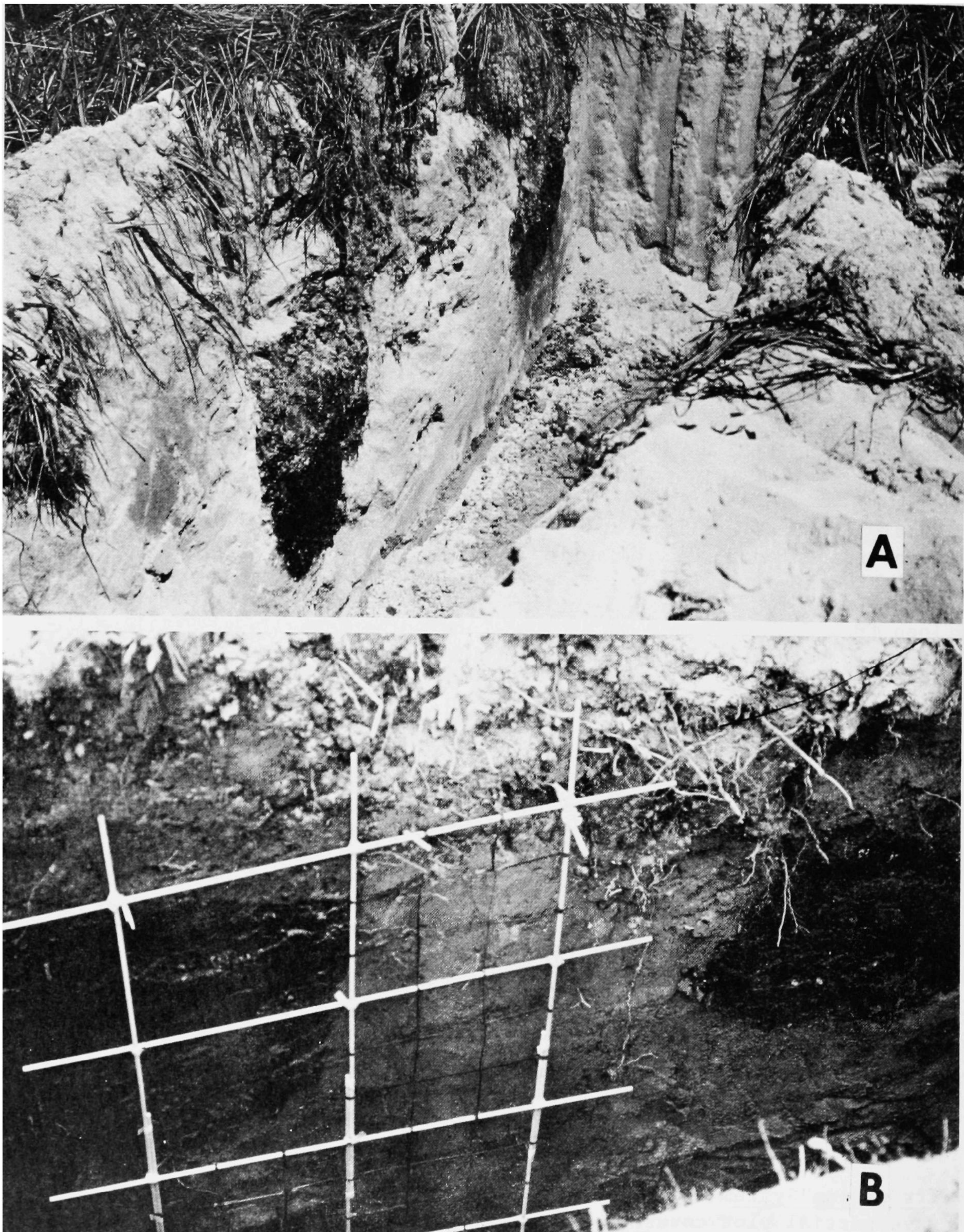


Figure 18. Excavation and sampling of entrenched sludge and surrounding soil.

Akron, 213 meters of ABC, and 427 meters of Wade-Rain 7.5-cm (3-inch) pipe with necessary fittings including valved-T fittings so that plots could be irrigated in sections. Rainbird sprinkler heads on 45-cm (18-inch) risers were spaced as needed. The system also included 183 meters (600 feet) of 10-cm (4-inch) Wade-Rain mainline feeder pipe. The irrigation water was pumped from the drainage pond.

Fencing -- The entire frontage of over 24 hectares (60 acres) along SCS Road was fenced with a 1.5 meter (5-foot) high galvanized farm fence. Thus access was limited to the plot and pond area.

Weather Station -- A weather station was installed for securing records on temperature, precipitation, and relative humidity in the plot area in July 1972. Precipitation at Beltsville is given in Table 6.

RESULTS AND DISCUSSION

Surface and Underground Water Analyses

Coliform and Viruses -- The results of surface and drainage water analyses for coliforms and viruses are presented in Tables 7 and 8. The data indicate that the coliform bacteria in the drainage pond for the most part are a result of surface runoff, because the drainage water in the subsurface tile in general showed little contamination relative to that in the surface tile. Note the increased contamination of the drainage water during late fall and winter. Movement into and/or persistence in drainage water was apparently greater during this cold period. From April to August 1973 there was little detectable total or fecal coliforms in the tile drains or pond. In comparison, the coliform levels in the stream were high. This stream contamination was apparently from some source other than the sludge plots.

Results of groundwater coliform and viral analyses are presented in Tables 9 and 10. Viral analyses of well water before and immediately after sludge entrenchment were negative. Since viral analyses are very difficult to perform and since the virus levels were so low in the sludge at time of entrenchment, further viral analyses of underground well water were not performed. Instead a series of laboratory studies were run to establish whether virus might move from entrenched sludges into and through the very sandy soil from the field entrenchment site (Section VII).

The wells were first sampled on April 24 to 28 before the entrenchment of sludge. Of the 27 sampled, 10 exhibited positive results for coliforms, but only one of these exhibited positive results for fecal coliforms. When the wells were resampled in early May, immediately after application of the sludge, only five remained positive for coliforms and none were positive for fecal coliforms. In subsequent tests there were still a few wells positive for total coliforms during late May and June 1972 and even a well with a low level of fecal coliforms. The presence of contamination in these wells prior to the

Table 6. PRECIPITATION AT BELTSVILLE

Date	Location of weather station		
	South farm	East farm	Trench plots
1972	Millimeters of rain		
Apr	139	137	-
May	124	138	-
June	269	262	
July	106	49	-
Aug	56	47	37
Sept	39	47	36
Oct	128	104	99
Nov	149	167	179
Dec	148	144	126
1973			
Jan	66	69	69
Feb	74	77	68
Mar	81	77	66
Apr	152	170	84
May	95	95	99
June	115	116	91
July	66	74	104
Aug	81	47	17
Sept	89	110	59
Oct	76	87	48
Nov	45	18	20
Dec	116	140	-

application of sludge, the general absence of fecal coliforms, and the disappearance of contamination in these wells with time shows that this initial contamination occurred during installation of the wells and was not a result of bacterial movement from the sludge.

In November 1972 (6 months after sludge application), water from well 22 exhibited MPN of nearly 1,000 total and 7 fecal coliforms per 100 ml. This contamination persisted through May 1973 with fecal coliforms occurring again only in April 1973. Well 22 was 2.4 meters (8 feet) in depth and located less than 3 meters (10 feet) from the raw-limed sludge plot IIIb. In March 1973, well 23, in the same general area as well 22 exhibited total coliform contamination in the water of 9 increasing to 1,000 MPN/100 ml in April and remaining at comparable levels through

Table 7. SUMMARY OF TOTAL COLIFORM ANALYSES OF SURFACE AND UNDERGROUND DRAINAGE WATERS

Date	Total coliforms, MPN/100 ml *			
	Surface and subsurface tile** (left)	Surface tile** (right)	Pond+	Stream++
Before sludge				
Apr 72	63-260	<2-20	-	49
After sludge				
May-Jun 72	8->16,000	<2-70	13-16,000	79->16,000
Jul-Oct 72	<2	<2-2	13-130	1,100-4,600
Nov 72-Mar 73	7-92,000	<3-130	31-4,300	43-2,300
Apr-Oct 73	<3-43 *+	<3-4	<3-93	93->11,000

* Coliform analyses by ARS and by the Maryland Department of Health and Mental Hygiene. Counts are based upon numbers of positive tubes in the most probable number method.

** Tile drain location shown in Figure 1.

\+ The pond location is shown in Figures 1, 9, and 11.

++ The stream drains land to the east and does not drain sludge plot area directly, rather it drains the pond which does drain the sludge plot area.

*+ The tile line was dry from Aug to Oct of 1973.

Table 8. SUMMARY OF FECAL COLIFORMS AND VIRAL ANALYSES OF SURFACE AND UNDERGROUND DRAINAGE WATERS

Date	Fecal coliforms, MPN/100 ml[*]				
	Surface and subsurface tile[+] (left)	Surface tile[+] (right)	Pond[++]	Stream[*+]	Virus[**]
Before sludge					
Apr 72	<2	<2	<2	-	negative
After sludge					
May-Jun 72	<2-16,000	<2	2-280	<2-1,700	negative
Jul-Oct 72	<2	<2	<2-13	33-110	-
Nov 72-Mar 73	<3-3,300[+*]	<3-2	<3-9	<3	-
Apr-Oct 73	<3	<3	<3-4	<3-460	-

* Coliform analyses by ARS or by the Maryland Department of Health and Mental Hygiene. Counts are based upon numbers of positive tubes in the most probable number method.

** Viral analyses by Maryland Department of Health and Mental Hygiene.

\+ Tile drain location shown in Figure 1.

++ The pond location is shown in Figures 1, 9, and 11.

*+ The stream drains land to the east and does not drain the sludge plot area directly, rather it drains the pond which does drain the sludge plot area.

+* 3,300 counts on Nov 1972 sampling only, rest of samplings <3 counts.

Table 9. SUMMARY OF TOTAL COLIFORM ANALYSES OF UNDERGROUND WELL WATER

Date	Wells* - total coliforms,** MPN/100 ml+			
	1-63 (except 16, 22, 23)	22 ++	23	16
Before sludge				
Apr 72	<2->1,609	<2	<2	<2
After sludge				
May-Jun 72	<2-1,700	<2-2	<2	<2
Jul-Oct 72	<2-70	<2	<2	<2
Nov 72-Mar 73	<3-1,100	73-1,100	<3-10	<3
Apr-Oct 73	<3->1,100			
Apr 73		2,400	1,100	10
May 73		1,100	1,100	<3
Jun 73		<3	<3	<3
Jul 73		240	<3	<3
Aug-Oct 73		-	<3	<3

* Well locations given in Figure 1; well 22, three meters away from raw-limed plot; well 23, eleven meters away from raw-limed plot; and well 16 is within a digested sludge plot.

** Coliform analyses by ARS or by the Maryland Department of Health and Mental Hygiene.

\+ Counts are based upon number of positive tubes in the most probable number method.

++ Well 22 was removed after July 1973.

Table 10. SUMMARY OF FECAL COLIFORM AND VIRAL ANALYSES OF UNDERGROUND WELL WATER

Date	Wells* fecal coliforms,** MPN/100 ml+				Virus++ 1-55
	1-63 (except 16, 22, 23)	22	23	16	
Before sludge					
Apr 72	<2-2	<2	<2	<2	negative
After sludge					
May-Jun 72	<2-5	<2	<2	<2	negative
Jul-Oct 72	<2-5	<2	<2	<2	-
Nov 72-Mar 73	<3-7	<3-7*+	<3	<3	-
Apr-Oct 73	<3	<3-75+*	<3	<3	-

* Well locations given in Figure 1; well 22, three meters away from raw-limed plot; well 23, eleven meters away from raw-limed plot; and well 16 is within a digested sludge plot.

** Coliform analyses by ARS or by the Maryland Department of Health and Mental Hygiene.

\+ Counts are based upon number of positive tubes in the most probable number method.

++ Viral analyses by Maryland Department of Health and Mental Hygiene.

*+ 7 fecal coliforms/100 ml were detected in Mar 73 only.

+* 75 fecal coliforms/100 ml were detected in Apr 73, subsequently <3/100 ml through Jul 73, then well 22 was removed.

May. No fecal coliforms were found in this well. Both these wells were found to be free of bacterial contamination in June 1973, but in July the total coliform MPN again increased to 240/100 ml.

Wells 22 and 23 failed air pressure tests in June 1974, which indicated probable grouting leaks. Well 22 was pulled out and examined. There were only 25 cm (10 inches) of grout rather than the planned 150 cm (5 feet). Also, the grouting mixture was apparently originally too wet; hence, strain occurred and a crack developed in the grout (Figure 6) through which contaminated surface water entered. In contrast, well 16, which is located directly within a digested sludge trenched area, did not fail the air pressure test and as yet its water has not shown coliform contamination. Data presented later in this report more strongly suggests that bacterial contamination of the underground well water did not occur by movement through the soil from the trenched sludge.

Ammonium- and Nitrate-Nitrogen -- In contrast with the results on bacterial movement, nitrogen apparently has moved in small quantities from the entrenched sludge through the soil into the subsurface drainage system. The nitrogen, however, was probably not moving significantly into underground well water. When fecal coliform and nitrate-nitrogen concentrations are compared in water from a subsurface drain line and in well 16 (Table 11), nitrate moved into the subsurface drainage water but fecal coliforms did not. Neither nitrate nor fecal coliforms moved into the wells.

As shown in Table 12, the greatest concentration of ammonium- and nitrate-nitrogen appeared in the pond (15 and 20 ppm respectively) and the stream (6 and 19 ppm respectively) within a few weeks after completing the trenching operations. The high concentrations probably reflected a general contamination of the soil surface with sludge and subsequent surface runoff into the pond. The relatively high concentrations in the subsurface tile may have been due to contamination from surface runoff entering cracks in the settling soil over the newly installed tile.

From July 1972 through August 1973 mineral nitrogen in the pond appeared to be a result of nitrogen contamination from both surface and subsurface drainage from the plots. In any case the concentrations of nitrogen in the pond and the stream have been at acceptable levels (Table 12) since June 1972. The nitrogen concentrations in the stream varied from a minimum of less than 1 ppm to a maximum of 6 ppm, while those in the pond varied from less than 1 ppm to a maximum of 4 ppm.

A summary of results of well water analyses for ammonium- and nitrate-nitrogen is given in Table 13. Of the 41 wells sampled from May 1972 through May 1973 only 19 showed ammonium- and nitrate-nitrogen concentrations above 1 ppm. Nine of these wells were adjacent to and 10 were distant from the trench area. The highest concentrations occurred in well 22 with from 6 to 21 ppm of nitrate-N occurring at various times. Well 22 was adjacent to a trench containing lime treated raw

Table 11. COMPARISON OF FECAL COLIFORMS AND NITRATE-NITROGEN IN SUBSURFACE DRAIN TILE (RIGHT) AND PLOT WELL 16

Date	Fecal coliforms MPN/100 ml		Nitrate - N mg/1	
	Tile	Well	Tile	Well
Before sludge				
Apr 72	<2	<2	<1	<1
After sludge				
May-Jun 72	<2	<2	<1-14	<1-1
Jul-Oct 72	<2	<2	<1-1	<1
Nov 72-Mar 73	<3-2	<3	5-10	<1
Apr-Oct 73	<3	<3	5-9	<1-4

sludge. It was also the well showing the highest coliform contamination. As previously mentioned, this well along with well 23 failed a casing leak test and new wells are being installed to determine the source of pollution.

With the exception of the first sampling concentration of 26 ppm in May 1972, well 23, in spite of coliform contamination, has shown only 2 ppm nitrate-N or less. In June the nitrate-N concentration in well 23 was less than 1 ppm. The initial high contamination, therefore, likely occurred during installation of the well.

Chloride and Conductivity -- Increases in chloride concentrations in three wells appeared to be associated with movement from entrenched sludge (Table 14). The increased chloride in well 16 was apparently a contamination from chloride moving through soil from entrenched sludge. Well 16 was located in the center of digested sludge in plot Ib. The concentration of chloride in well 16 peaked in November 1973 and then decreased. In contrast the nitrate concentrations did not increase. Movement of chloride into the well without similar movement of nitrate perhaps occurred because nitrate first had to be formed by bacterial action and because appreciable amounts of nitrate may have been removed by denitrification.

Table 12. SUMMARY OF NITROGEN* ANALYSES OF SURFACE AND UNDERGROUND DRAINAGE WATERS

Date	Nitrogen, mg/l							
	Surface and Subsurface tile (left)		Subsurface tile (right)		Pond		Stream	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Before sludge								
Apr 72	1	1	<1	<1	<1	<4	-	-
After sludge								
May-Jun 72	<1-1	<1-16	<1-5	<1-4	<1-22	<1-19	<1-1	1-11
Jul-Oct 72	2	<1	1-2	<1-1	<1	<1	<1-1	<1
Nov 72-Mar 73	<1	1-2	7-12	5-10	1-2	1-2	2-4	2-4
Apr-Nov 73	<1-7**	2-8**	4-15	5-9	<1-2	<1-4	<1-3	5-6

* Nitrogen analyses by ARS and Maryland Environmental Service.

** Left tile dry Jul-Nov 73.

Table 13. SUMMARY OF NITROGEN* ANALYSES OF UNDERGROUND WELL WATERS

Date	Nitrogen in wells, mg/l: 1-63 NH_4-N (except 16, 22, 23)	1-63 NO_3-N (except 16, 22, 23)	Date	22** NH_4-N	22** NO_3-N	23 NH_4-N	23 NO_3-N	16 NH_4-N	16 NO_3-N
Before sludge									
Apr 72	<1	<1-5		<1	<1	<1	<1-29	<1	<1
After Sludge									
May-Jun 72	<1-8	<1-14		<1	<1	<1	<1-1	<1	<1-1
Jul-Oct 72	<1-2	<1-9		<1	<1	<1	<1	<1	<1
Nov 72-Mar 73	<1-7	<1-5		<1-3	14-21	<1	1-2	<1	<1
Apr-Oct 73	<1-2	<1-15		<1	<1-9	<1	<1-2	<1	<1-4
			Apr 73	<1	<1				
			May 73	<1	6				
			Jun 73	<1	9				
			Jul 73	<1	4				

* Nitrogen analyses by ARS and the Maryland Environmental Service.

**Well 22 removed after Jul 73

Table 14. CHLORIDE ANALYSES OF UNDERGROUND WELL WATER

Date	Wells*- chloride, mg/l						
	1-63**	16	21	22	23	42	62
Before sludge							
Apr 72	0.5-24	1	1	2	2		24
After sludge							
May-Jun 72	0.5-18	2	2	2	2	42	21
Jul-Oct 72	0.7-18		-		2	38	-
Nov 72-Mar 73	-		-	47-95	4-8		27
Apr-Oct 73	<1-18	28-72	73-36	64-39++	4-10	35-41	24
Nov-Dec 73	1-52+	89-64	-	-	6		64
Jan 74	1-12	49	21	-	6	33	20

* Well locations are given in Figure 1; well 16 is within a digested sludge plot; wells 21, 22, 23 are 3 to 12 m (10 to 40 ft) from sludge plots; well 42 is 550 m to the north of the entrenchment plots; and well 62 is 150 to 180 m to the southeast.

** Excluding wells 16, 21, 22, 23, 42, 62.

\+ Well 40 contained 52 ppm in Dec 72 which decreased to 8 ppm in Jan 72.

++ Well 22 was removed after Jul 72.

The increase in chloride in well 22 appeared to be both from surface as well as subsurface contamination (see discussion on well 22 in previous section on nitrogen). On the other hand increases in chloride in well 21, located about 12 meters (40 feet) from plot IIb, apparently were real. The chloride concentration decreased after peaking in May 1973.

Continued elevated levels of chloride in wells 42 and 62, located several hundred yards each from the plot, were indicative of contamination from some other source. Well 23 was not contaminated with either chloride or nitrate.

Measured conductivities of well water were much more erratic than measured chloride concentrations (Table 15). Water from wells 3, 11, 34,

Table 15. CONDUCTANCE OF UNDERGROUND WELL WATER

Date	Wells*- conductivity μmhos/cm^2						
	1-63**	16	21	22	23	42	62
Before sludge							
Apr 72	22-200	-	55	50	45	-	-
After sludge							
May-Jun 72	23-160	60	70	60	60	320	120
Jul-Oct 72	28-160	-	-	-	45	320	-
Nov 72-Mar 73	28-313	44-58	173-202	308-353	44-57	-	125
Apr-Oct 73	17-335	70-130	201-161	254-151+	71-50	82-315	110
Nov-Dec 73	20-220	180	-	-	-	-	120
Jan 74	20-280	200	110	-	60	300	120

* Well locations are given in Figure 1; well 16 is within a digested sludge plot; wells 21, 22, 23 are 3 to 12 m from sludge plots; well 42 is 350 m to the north of the entrenchment plots; and well 62 is 150 to 180 m to the southwest.

** Excluding wells 16, 21, 22, 23, 42, 62.

\+ Well 22 was removed after Jul 72.

and 40 had elevated conductivities at one time or another, revealing a wide range in conductivities for the monitoring wells. The wide range in conductivity measurements in these wells probably had nothing to do with contamination from sludge. In other wells where chloride concentrations in the water increased as well as conductivity, such as well 16, the increase may have been related to contamination from sludge. The increase in conductivity in well 16, however, did not parallel the behavior of chloride. From the available data, therefore, it is not possible to relate conductivity of well water to contamination from sludge.

Chloride concentrations increased somewhat in drainage and pond water after entrenchment of sludge (Table 16), probably caused by movement of chloride from the sludge. Conductivities may also have increased after sludge entrenchment (Table 17), but the measurements exhibited considerable variability.

Other Chemical Analyses -- A series of chemical analyses were performed on water from selected wells, the drain lines, the pond, and the stream. Little change occurred in any of the major or minor chemical elements or constituents (Tables 16, 17, 18, and 19). The native concentrations of heavy metals (Table 18) in fact were quite low and have not increased.

Concentrations of all measured biological and chemical properties of underground well water and drainage water have nearly always been less than would be permitted in public water supplies (Table 20). In addition, during the study, all underground well water met drinking water standards.

Entrenched Sludge and Surrounding Soil

Introduction -- Periodic chemical and biological measurements of water under and draining the trenched experimental plots showed that some sludge components moved through the soil. While indicator fecal coliform organisms and heavy metals remained at low concentrations in plot wells and drainage waters 19 months after sludge entrenchment, total coliform microorganisms, nitrate, ammonium, and chlorides increased somewhat. While the observations strongly suggest that the total coliform microorganisms moved from the sludge down into the soil, these microorganisms could have come from many sources other than sludge and they can survive and reproduce in the soil. There is abundant evidence in the literature that nitrogen, ammonium, and chlorides move through the soil, but these materials also may come from places other than sludge, e.g. from fertilizer such as that used around the plot area. Thus a more direct study of the entrenched sludge and a determination of possible movement of components through the soil from the entrenched sludge was needed. Cross sections of entrenched sludge and soil were therefore exposed periodically for observation and sampled for analysis (Figure 18). Later data on trench cross section analysis than discussed in the main body of the text may be found in the Appendix.

Table 16. ANALYSES* OF SURFACE AND UNDERGROUND WELL WATER FOR SO_4, PO_4, Cl, NH_4, AND NO_3

Source	Date	SO_4	PO_4	Cl	NH_4	NO_3
		mg/l				
Underground well** water	Apr 72 (Before)+	4-60	<0.05-1.95	0.2-7.4	0	<1-29
	May 72 (After)++	4-66	<0.01-0.15	1.0-7.1	0	4-14
	Jun 72	6-38	0.02-0.06	0.5-6.4	0	<1-1
	Jan 73	-	0.01-0.08	2.5-8.0	0-7	1-5
	Oct 73	2-16	<0.01-0.01	5.0-44.0	1	0-1
Surface and subsurface (left) tile drain	Apr 72 (Before)	4	<0.05	1.0	1	<1
	May 72 (After)	12	0.01	3.7	<1	16
	Jun 72	13	0,02	1.7	<1	1
	Jan 73	-	<0.01	12.6	<1	1
Subsurface (right) tile drain	Apr 72 (Before)	8	<0.05	9.6	<1	<1
	May 72 (After)	16	<0.01	11.9	<1	3
	Jun 72	16	0.02	11.3	<1	1
	Jan 73	-	<0.01	40.0	7	5
	Jul 73	29	0.15	30.0	6	8
	Oct 73	24	<0.01	22.0	7	5
Pond	Jan 73 (After)	-	<0.01	15.0	2	2
	Oct 73	29	0.01	33.0	<1	5
Stream	Apr 72 (Before)	4	<0.05	1.5	<1	4
	May 72 (After)	18	0.03	17.3	<1	19
	Jun 72	23	0.03	13.4	<1	2
	Oct 73	8	0.01	32.0	<1	1

* Analyses by Maryland Department of Water Resources.
** Range of values for wells 4, 10, 11, 21, 23, 26, 61.
\+ Before sludge placement.
++ After sludge placement.

Table 17. ANALYSES* OF SURFACE AND UNDERGROUND WELL WATER FOR: K, Na, Ca, Mg, CONDUCTANCE AND pH

Source	Date	K	Na	Ca	Mg	Specific conductance µmhos/cm	pH
		mg/l					
Underground well** water	Apr 72 (Before)+	1.0-71.0	0.8-9.8	1.9-3.6	0.8-2.6	4-311	4.6-6.7
	May 72 (After)++	0.6-2.5	0.5-7.0	1.8-4.2	1.2-2.7	49-194	4.2-7.4
	Jun 72	1.0-50.0	0.8-11.0	1.3-3.8	1.3-3.8	3-160	4.6-6.5
	Jan 73	1.2-39.8	0.4-15.7	1.1-2.6	0.8-2.8	-	-
	Oct 73	1.3-5.1	1.0-3.6	1.0-4.3	1.2-4.2	40-166	4.4-7.0
Surface and subsurface (left) tile drain	Apr 72 (Before)	1.0	0.8	2.8	1.4	53	5.6
	May 72 (After)	1.1	1.0	4.2	2.0	70	6.3
	Jun 72	1.8	1.0	3.4	1.7	47	5.4
	Jan 73	1.5	1.3	5.7	3.1	-	-
Subsurface (right) tile	Apr 72 (Before)	1.5	5.5	4.4	1.5	88	5.6
	May 72 (After)	1.1	5.0	7.1	1.9	97	5.4
	Jun 72	2.3	4.1	5.3	1.7	76	5.2
	Jan 73	2.7	4.7	20.0	4.5	-	-
	Jul 73	4.2	4.7	1.9	17.2	220	6.6
	Oct 73	2.5	1.3	14.7	18.7	215	6.7
Pond	Jan 73 (After)	2.3	2.6	9.9	2.2	-	-
	Oct 73	3.4	3.8	17.0	16.5	185	4.9
Stream	Apr 72 (Before)	0.8	7.5	2.7	1.6	116	4.4
	May 72 (After)	1.0	9.4	3.5	2.0	124	4.6
	Jun 72	2.3	5.0	5.4	1.4	77	4.9
	Oct 73	1.6	7.5	10.6	7.2	114	6.3

* Analyses by Maryland Department of Water Resources.
** Range of values for wells 4, 10, 11, 21, 23, 26, 61.
\+ Before sludge placement.
++ After sludge placement.

Table 18. ANALYSES* OF SURFACE AND UNDERGROUND WELL WATER FOR: Fe, Mn, Zn, Cd, Cr, Ni, Pb, Hg, AND Cu

Source	Date	Fe	Mn	Zn	Cd	Cr	Ni	Pb	Hg	Cu
		mg/l								
Underground well** water	Apr 72 (Before)+	<0.05-28.5	<0.05-<0.1	<0.025	<0.05	<0.05	<0.01	<0.05	<0.0001-0.0004	<0.025
	May 72 (After)++	<0.01	<0.05	<0.025	<0.025	<0.05	<0.05	<0.25	<0.0001	<0.05
	Jun 72	<0.05-7.6	<0.05-0.2	<0.025	<0.025	<0.1	-	<0.25	-	<0.05
	Jan 73	<0.01-3.4	<0.05	<0.025	<0.025	<0.05	-	<0.1	<0.0001	<0.025
	Oct 73	<0.05-4.6	<0.02-0.8	<0.05-0.05	<0.025	<0.05	-	<0.1	<0.0001	<0.05
Surface and subsurface (left) tile drain	Apr 72 (Before)	<0.05	<0.05	<0.025	<0.05	<0.05	<0.01	<0.05	<0.0001	<0.025
	May 72 (After)	0.5	<0.05	<0.025	<0.025	<0.05	<0.05	<0.25	<0.0001	<0.05
	Jun 72	0.4	<0.05	<0.025	<0.025	<0.1	-	<0.25	-	<0.05
	Jan 73	<0.1	0.2	<0.025	<0.025	<0.05	-	<0.1	<0.0001	<0.025
Surface (right) tile drain	Apr 72 (Before)	<0.05	<0.05	<0.025	<0.05	<0.05	<0.01	<0.05	<0.0001	<0.025
	May 72 (After)	<0.1	<0.05	<0.025	<0.025	<0.05	<0.05	<0.25	<0.0001	<0.05
	Jun 72	1.2	0.1	<0.025	<0.025	<0.1	-	<0.25	-	<0.05
	Jan 73	9.6	0.9	<0.025	<0.025	<0.05	-	<0.1	<0.0001	<0.025
	Jul 73	0.6	1.0	<0.05	<0.025	<0.05	-	<0.1	<0.0001	<0.05
	Oct 73	2.2	1.0	<0.05	<0.025	<0.05	-	<0.1	<0.0001	<0.05
Pond	Jan 73 (After)	1.3	0.2	<0.025	<0.025	<0.05	-	<0.1	<0.0001	<0.025
	Oct 73	<0.05	0.9	<0.05	<0.025	<0.05	-	<0.1	<0.0001	<0.05
Stream	Apr 72 (Before)	0.2	<0.05	<0.025	<0.05	<0.05	<0.01	<0.05	<0.0001	<0.025
	May 72 (After)	0.5	<0.05	<0.025	<0.025	<0.05	<0.05	<0.25	<0.0001	<0.05
	Jun 72	1.0	0.1	0.04	<0.025	<0.1	-	<0.25	-	<0.05
	Oct 73	<0.05	0.1	<0.05	<0.025	<0.05	-	<0.1	<0.0001	<0.05

* Analyses by Maryland Department of Water Resources
** Range of values for wells 4, 10, 11, 21, 23, 26, 61.
\+ Before sludge placement.
++ After sludge placement.

Table 19. ANALYSES* OF SURFACE AND UNDERGROUND WELL WATER FOR INORGANIC AND ORGANIC CARBON AND DISSOLVED SOLIDS

Source	Date	Inorganic carbon	Organic carbon	Dissolved solids
		mg/l		
Underground well** water	Apr 72 (Before)+	<1-14	2-87	53-204
	May 72 (After)++	1-6	3-159	58-232
	Jun 72	1-14	1-82	14-106
	Jan 73	4-21	1-26	-
	Oct 73	2-3	<1-4	8-90
Surface and subsurface (left) tile drain	Apr 72 (Before)	2	1	60
	May 72 (After)	1	3	66
	Jun 72	6	1	23
	Jan 73	3	1	-
Surface (right) tile drain	Apr 72 (Before)	1	2	62
	May 72 (After)	1	1	78
	Jun 72	6	1	65
	Jan 73	15	6	
	Jul 73	3	2	92
	Oct 73	11	2	56
Pond	Jan 73 (After)	4	2	
	Oct 73	4	12	180
Stream	Apr 72 (Before)	<1	2	80
	May 72 (After)	1	5	92
	Jun 72	1	3	38
	Oct 73	2	1	88

* Analyses by Maryland Department of Water Resources.

** Range of values for wells 4, 10, 11, 21, 23, 26, 61.

\+ Before sludge placement.

++ After sludge placement.

Table 20. SURFACE WATER CRITERIA FOR PUBLIC WATER SUPPLIES*

Constituent or characteristics	Permissible criteria
Microbiological:	
Coliform Organisms	20,000/100 ml**
Fecal coliforms	2,000/100 ml**
Inorganic chemicals:	mg/1
Ammonia	0.5 (as N)
Cadmium	0.10
Chloride	250
Chromium, hexavalent	0.05
Copper	1.0
Lead	0.05
Nitrates	10 (as N)
Nitrites	1.0 (as N)
pH (range)	5.0 - 9.0
Sulfate	250

* Data taken from Water Quality Criteria, Report of the National Technical Advisory Committee to the Secretary of Interior, 1972.

** Microbiological limits are monthly arithmetic averages based upon an adequate number of samples.

Movement and Persistence of Coliforms and Salmonellae -- From freshly exposed cross-sections of entrenched sludge, samples were selected from the sludge, from depths below the sludge, and at distances from the side of the sludge. The soil samples from the sides were selected along a line midway between the top and bottom of the trench. Samples below the trench were selected along a line midway between the sides of the trench. The sampling was initiated 3 months after entrenchment and continued for the remainder of the study. The data are summarized in Tables 21, 22, 23, and 24.

Fecal coliform and salmonella microorganisms were not detected in the soil at distances greater than 15 cm (6 inches) below or to the side of the entrenched sludge. If fecal coliform and salmonella microorganisms moved distances greater than 15 cm from the entrenched sludge, the organisms either were inviable or undetectable by the procedures used. Total coliform microorganisms, however, were detected at distances of 60 cm (24 inches) from the trenches. The total coliform bacteria had apparently moved out from the entrenched sludge into the surrounding soil. These results suggested that the total coliform microorganisms detected in the subsurface drainage water could have moved from the entrenched sludge through the soil when the plots were close to the drain lines.

The total and fecal coliform bacteria present in the digested sludge of the 60 x 60 cm trenches decreased in number with time. The salmonella bacteria, not measured until 14 months after sampling, were always below the levels of detection (Table 21). In the 60 x 120 cm digested trenches, the fecal coliforms and salmonella bacteria counts were low throughout the sampling periods. Total coliform counts were low the 7th month, but were found to have increased by the 12th and 17th months (Table 22).

Although total and fecal coliforms initially were not detected in the raw-limed sludge, they were detected 2.5 and 15 cm (1 and 6 inches) below the trench. Apparently these organisms, unable to grow in the sludge, were able to grow in the soil close to the sludge. A possible reason was that an inoculated substrate, moving from the sludge, decreased in pH as it contacted the soil. The increase in numbers of total and fecal coliforms in the raw-limed sludge itself that occurred in the 10th month after entrenchment and persisted into the 17th month for the total coliforms (Table 23), may have also been a result of a decrease in pH of the sludge as the $Ca(OH)_2$ was converted to $CaCO_3$ (Table 25). Total and fecal coliforms and salmonellae were still present in the 60 x 120 cm raw-limed liquid sludge trenches after 19 months (Table 24).

In summary, there was little threat of movement of bacterial pathogens from the entrenched sludge. Survival in limed sludge probably depended upon the ability of bacteria to regrow as the alkalinity of the sludge was reduced with time. Since most pathogens are incapable of growing outside their hosts except in special media, liming should provide effective control. For total and fecal coliforms, survival in both

Table 21. BACTERIA IN ENTRENCHED (60 x 60 cm) DIGESTED SLUDGE AND IN SURROUNDING SOIL

Plot		Ia		Ia			Ib		
Date		8/3/72		9/27/72			7/3/74		
Months		3		4			14		
Determination*		TC	FC	TC	FC		TC	FC	S
		MPN/g dry wt							
Location									
Trenched sludge		>41,000	>41,000	330	<0.5	(55,35)**	3,500	<14	<14
						(55,55)	7,080	<14	<14
						(35,35)	64,600	10,300	<14
Below, cm									
2	55,62**	1,600	220	100	<0.3		8	<6	<6
15	55,75	3,900	8.7	<0.3	<0.3		18	<6	<6
30	55,90	<2	<2	<0.3	<0.3		87	<6	<7
45	55,105	-	-	<0.3	<0.3		<6	<6	<6
60	55,120	<2	<2	-	-		-	-	-
100	55,160	2.3	<2	-	-		-	-	-
Side, cm									
5	25,35	-	-	<0.3	<0.3		<6	<6	<6
15	15,35	-	-	<0.3	<0.3		<6	<6	<6
25	5,35	-	-	16	<0.3		<6	<6	<6

* TC = total coliform, FC = fecal coliform, and S = salmonellae.

** These locations are given in Figure 19.

Continued

Table 21 (continued). BACTERIA IN ENTRENCHED (60 x 60 cm) DIGESTED SLUDGE AND IN SURROUNDING SOIL

Plot	Ia			Ia			V Control		
Date	10/17/73			11/27/73			11/14/73		
Months	17			18			18		
Determination	TC	FC	S	TC	FC	S	TC	FC	S
	MPN/g dry wt								
Location									
Trenched sludge	(A)[+] <4	<4	<4	(A)[+] 120	<5	<5	(X)[++] 46	<3	<3
	(B) 32,000	<6	<6	(B) 5,800	<7	<7	(Y) <4	<3	<3
	(C) 68	<8	<8	(C) 720	<8	<8	(Z) <3	<3	<3
Below, cm									
7 55,62	<3	<3	<3	<3	<3	<3	<3	<3	<3
15 55,75	<3	<3	<3	<3	<3	<3	<3	<3	<3
30 55,90	<3	<3	<3	<3	<3	<3	<3	<3	<3
45 55,105	<3	<3	<3	<3	<3	<3	<3	<3	<3
60 55,120	<3	<3	<3	<3	<3	<3	<3	<3	<3
Side, cm									
5 25,35	<3	<3	<3	<3	<3	<3	<3	<3	<3
15 15,35	<3	<3	<3	<3	<3	<3	<3	<3	<3
25 5,35	<3	<3	<3	<3	<3	<3	<3	<3	<3

\+ Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration.

++ Region X was the top 5 cm of the trenched control, region Y was the next 20 cm of the control trench, and region Z was the bottom 35 cm of the control trench.

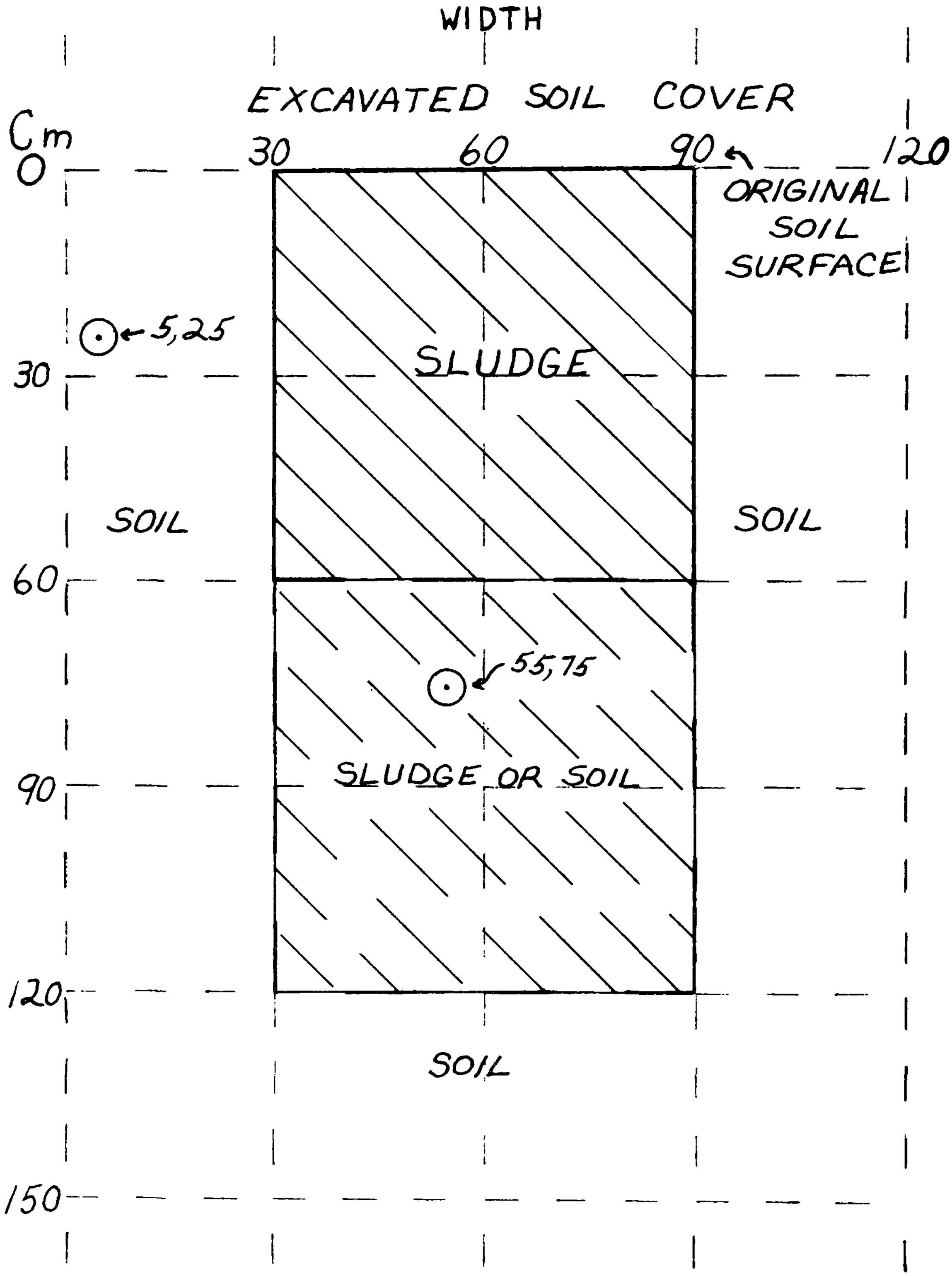


Figure 19. Schematic representation of entrenched sludge and surrounding soil showing labeling scheme in inches.

Table 22. BACTERIA IN ENTRENCHED (60 x 120 cm) DIGESTED SLUDGE AND IN SURROUNDING SOIL

Plot		IIa		IIb				IIb				IIb		
Date		8/16/72		12/27/72				5/16/73				11/1/73		
Months		3		7				12				17		
Determination*		TC	FC	TC	FC	S		TC	FC	S		TC	FC	S
		MPN/g dry wt												
Location														
Trenched sludge		20,000	230	0.9	<0.9	<9	(55,62)**	112,000	9	14	(A)+	560	<4	<4
							(55,119)	22,800	13	<10	(B)	27,000	19	<4
							(35,35)	32,100	57	<7	(C)	<7	<7	<7
Below, cm														
2	55,122**	2.2	0.4	3,400	<0.3	<4		<4	<4	<7		3	<3	<3
15	55,135	3.8	0.2	<0.3	<0.3	<4		<4	<4	<6		<3	<3	<3
30	55,155	<0.2	<0.2	<0.3	<0.3	<3		238	37	<6		<3	<3	<3
60	55,180	3.8	<0.2	10	<0.3	<3		-	-	-		<3	<3	<3
Side, cm														
5	25,60	-	-	4,800	<0.3	<4		75	<4	<7		81	<3	<3
15	15,60	-	-	<0.3	<0.3	<3		372	<4	<7		80	10	<3
25	5,60	-	-	<0.3	<0.3	<3		522	<4	<7		<3	<3	<3

* TC = total coliform, FC = fecal coliform, S = salmonellae

** These locations are given in Figure 19.

\+ Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration.

Table 23. BACTERIA IN ENTRENCHED (60 x 60) RAW-LIMED SLUDGE AND IN SURROUNDING SOIL

Plot		IIIa		IIIa		IIIa	
Date		8/2/72		8/10/72		9/6/72	
Months		3		3		4	
Determination*		TC	FC	TC	FC	TC	FC
		MPN/g dry wt					
Location							
Trenched sludge		<75	negative	<1	negative	<1,<1	<1,<1
Below, cm							
2	55,62**	220	190	<15,000	25	250,450	<0.3,<0.3
15	55,75	380	190	<15,000	<0.2	<0.3,212	<0.3,<0.3
30	55,90	19	<2	2.5	<2	<0.3,10	<0.3,<0.3
45	55,105	2.5	<2	4.4	<2	<0.4,2.7	<0.3,<0.3
60	55,120	-	-	-	-	-	-
Side, cm							
5	25,35					5,100;83,000	<0.3,<0.3
15	15,35					<0.3;1,000	<0.3,<0.3
25	5,35					<0.3;1,000	<0.3,<0.3

* TC = total coliform, FC = fecal coliform, S = salmonellae

Continued

Table 23 (continued). BACTERIA IN ENTRENCHED (60 x 60) RAW-LIMED SLUDGE AND IN SURROUNDING SOIL

Plot		IIIa			IIIa			IIIa	
Date		12/19/72			3/7/73			10/30/73	
Months		7			10			17	
Determination	TC	FC	S	TC	FC	S	TC	FC	S
	MPN/g dry wt								
Location									
Trenched sludge	320	<0.4	<4	29,000	5,400	<11	(A)* <3	<3	<3
				16,000	4,100	<11	(B) 180,000	<4	<4
				8,500	3,400	<11	(C) 590	<9	<9
Below, cm									
2 55,62**	1	<0.3	<3	12	<3	100	10	<3	<3
15 55,75	0.4	<0.3	<3	49	<4	<4	<3	<3	<3
30 55,90	<0.3	<0.3	<3	87	<4	<4	<3	<3	<3
45 55,105	27	<0.3	<3	-	-	-	<3	<3	<3
60 55,120	<0.3	<0.3	<3	-	-	-	<3	<3	<3
Side, cm									
5 25,35	27	<0.3	<3	84	<3	<3	4	<3	<3
15 15,35	<0.3	<0.3	<3	<3	<3	<3	<3	<3	<3
25 5,35	27	<0.3	<3	<3	<3	<3	<3	<3	<3

** These locations are given in Figure 19.

\+ Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration.

Table 24. BACTERIA IN ENTRENCHED (60 x 120 cm) RAW-LIMED LIQUID SLUDGE AND IN SURROUNDING SOIL

Plot			IVa	
Date			12/6/73	
Months			19	
Determination*		TC	FC	S
		----------	MPN/g dry wt	----------
Location				
Trenched sludge	(A) +	-	-	-
	(B)	880	29	44
	(C)	9	<7	1,300
	(D)	<3	<3	<3
Below, cm				
2	55,122**	<3	<3	<3
15	55,135	<3	<3	<3
30	55,150	<3	<3	<3
60	55,180	<3	<3	<3
Side, cm				
5	25,60	4	4	<3
15	15,60	<3	<3	<3
25	5,60	<3	<3	<3

* TC = total coliform, FC = fecal coliform, S = salmonellae

** These locations are given in Figure 19.

\+ Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration. Region D is the area immediately below the sludge where top soil and/or subsoil plus leachate from liquid sludge apparently penetrated (2 to 15 cm) into the soil.

Table 25. THE pH OF RAW-LIMED SLUDGE INITIALLY AND WITH TIME AFTER ENTRENCHMENT IN PLOT IIIa

Date	6/72	8/2/72		12/19/72		3/7/73		10/30/73		12/7/73	
Months after entrenchment	0		3		7		10		17		19(IVa)
Mean	>11.5		9.6		7.9		8.9		6.7		7.4
By location	---	55,35*	11.3	55,35	7.9	35,15	7.6	A**	4.1	-	---
		55,55	7.9			35,35	8.5	B	6.4	B+	7.3
						35,55	7.5	C	7.4	C	7.4
						55,35	11.2				
						55,55	7.8				

* Locations given in Figure 19.

** Zones given in Figure 20B

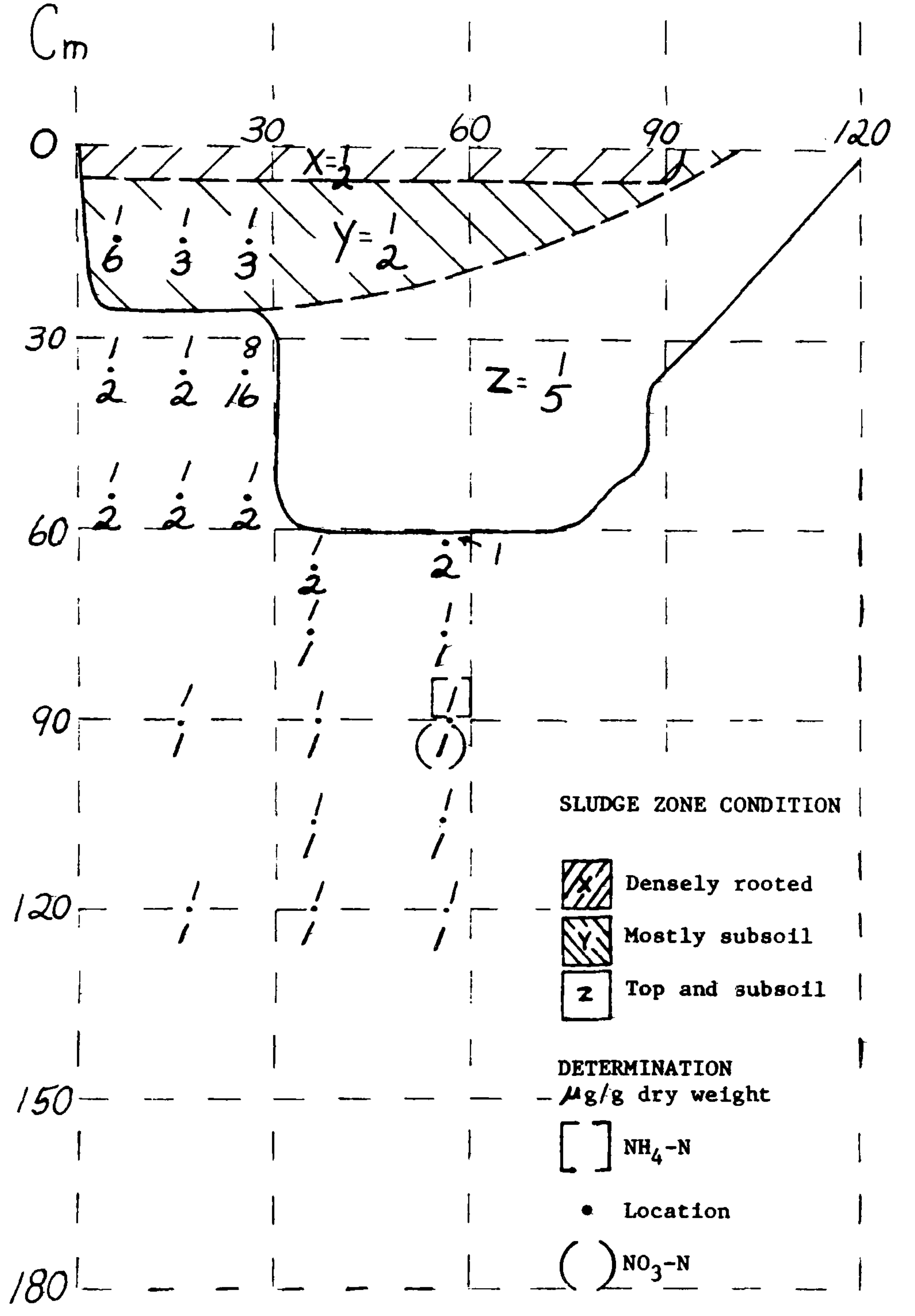
\+ Zones given in Figure 20E

Table 26. NITRATE-NITROGEN MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location	Nitrate-N, μg/g dry weight in sludge							
	Raw 60 x 60 cm		Raw liquid 60 x 120 cm		Digested 60 x 60 cm		Digested 60 x 120 cm	
	Months after entrenchment							
	3	17	19	3	17	19	3	17
Trenched sludge (B)*	280	1900	58	15	1200	1000	15	600
(C)**	100	110	60	-	40	60	5	40
Below, cm								
2	93	243	60	146	25	54	3	3
15	28	45	51	20	21	47	3	3
30	1	7	56	3	12	28	2	3
45	1	7	67	3	15	27	2	5
60	-	6	22	-	8	19	-	2

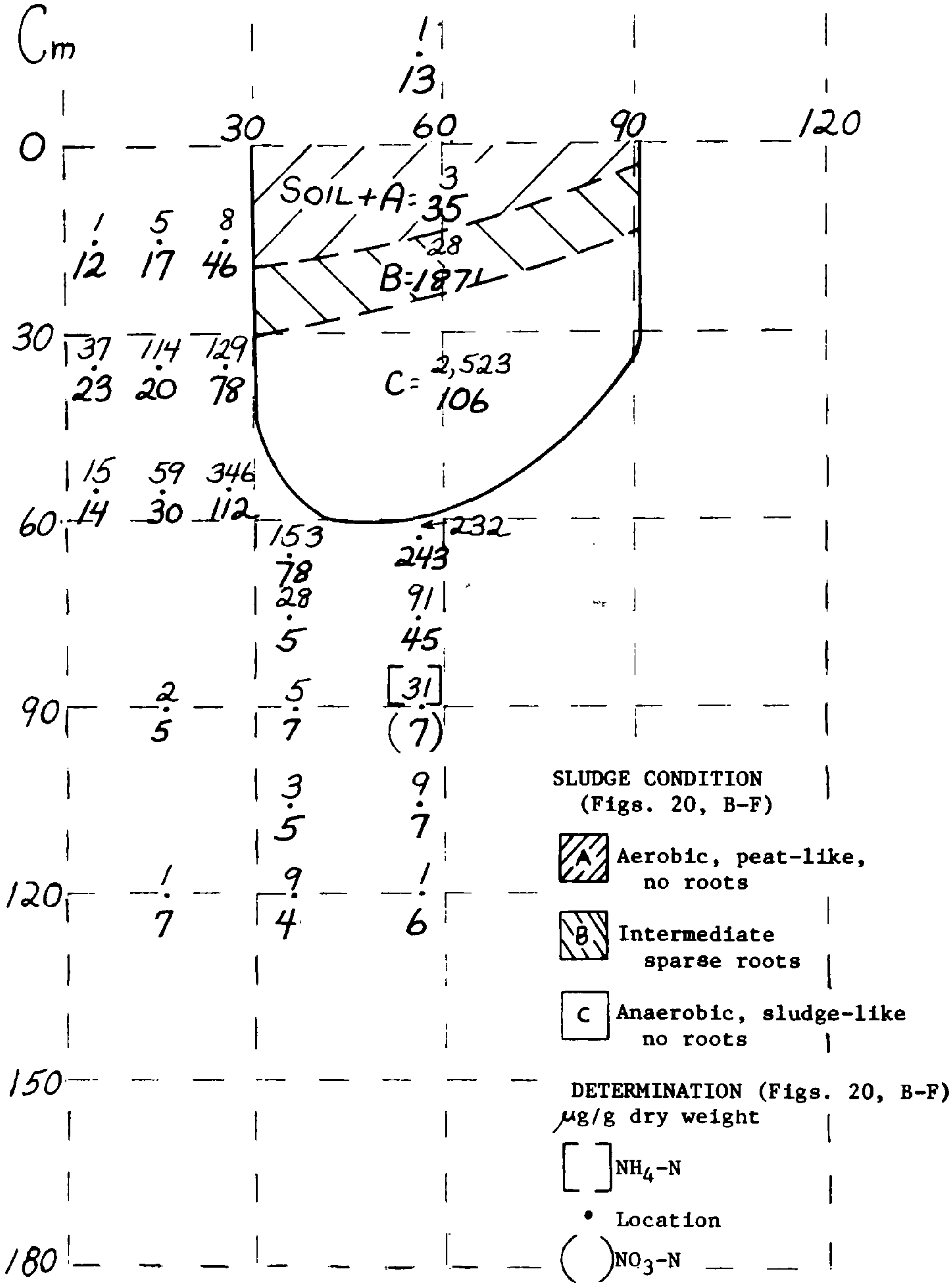
* Mostly aerobic sludge.

** Anaerobic sludge.



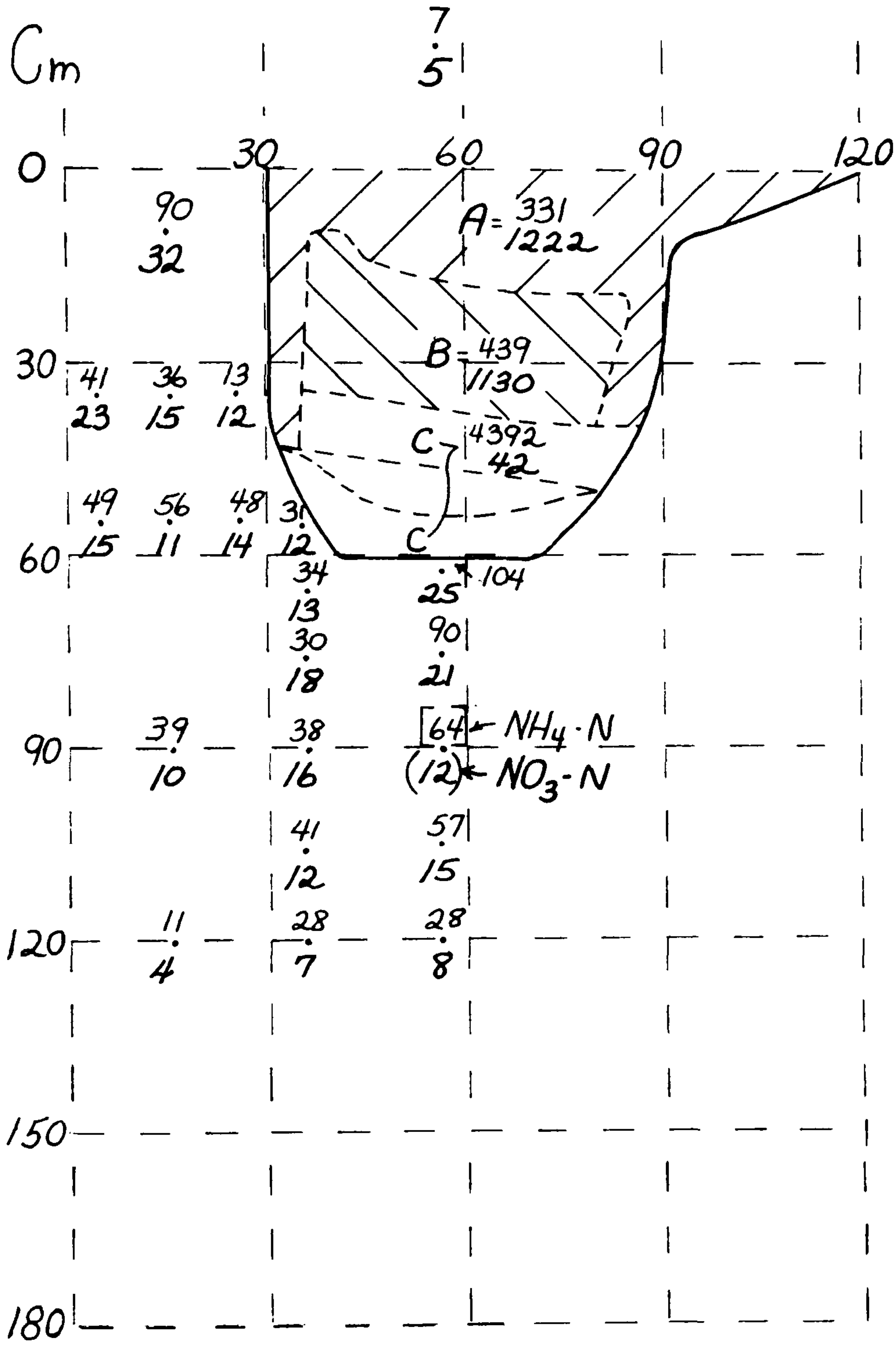
(A) Control (Va).

Figure 20. Ammonium- and nitrate-nitrogen in and around entrenched sludge 17 months after entrenchment.



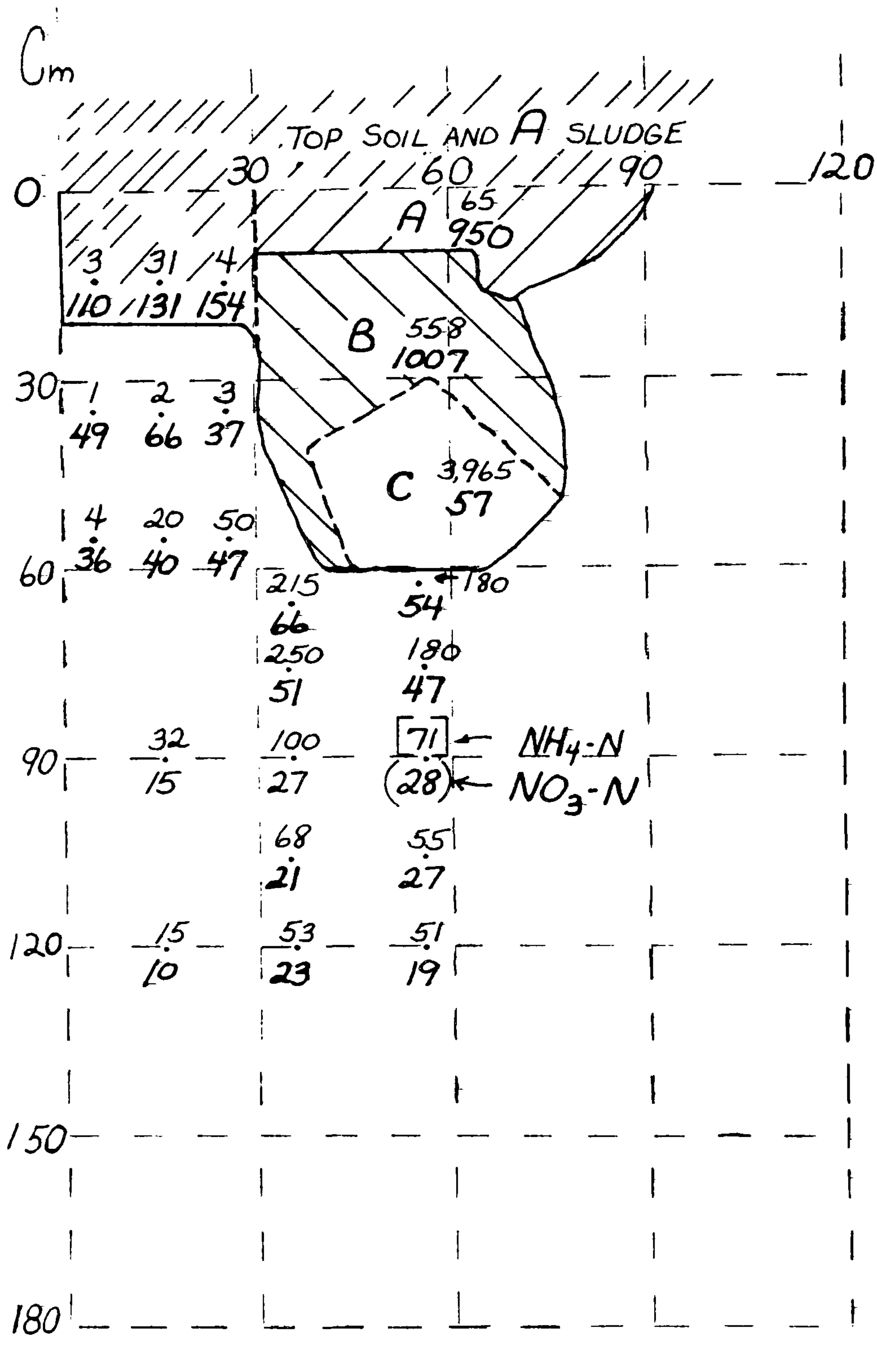
(B) Raw-limed (IIIa).

Figure 20 (continued). Ammonium- and nitrate-nitrogen in and around entrenched sludge 17 months after entrenchment.



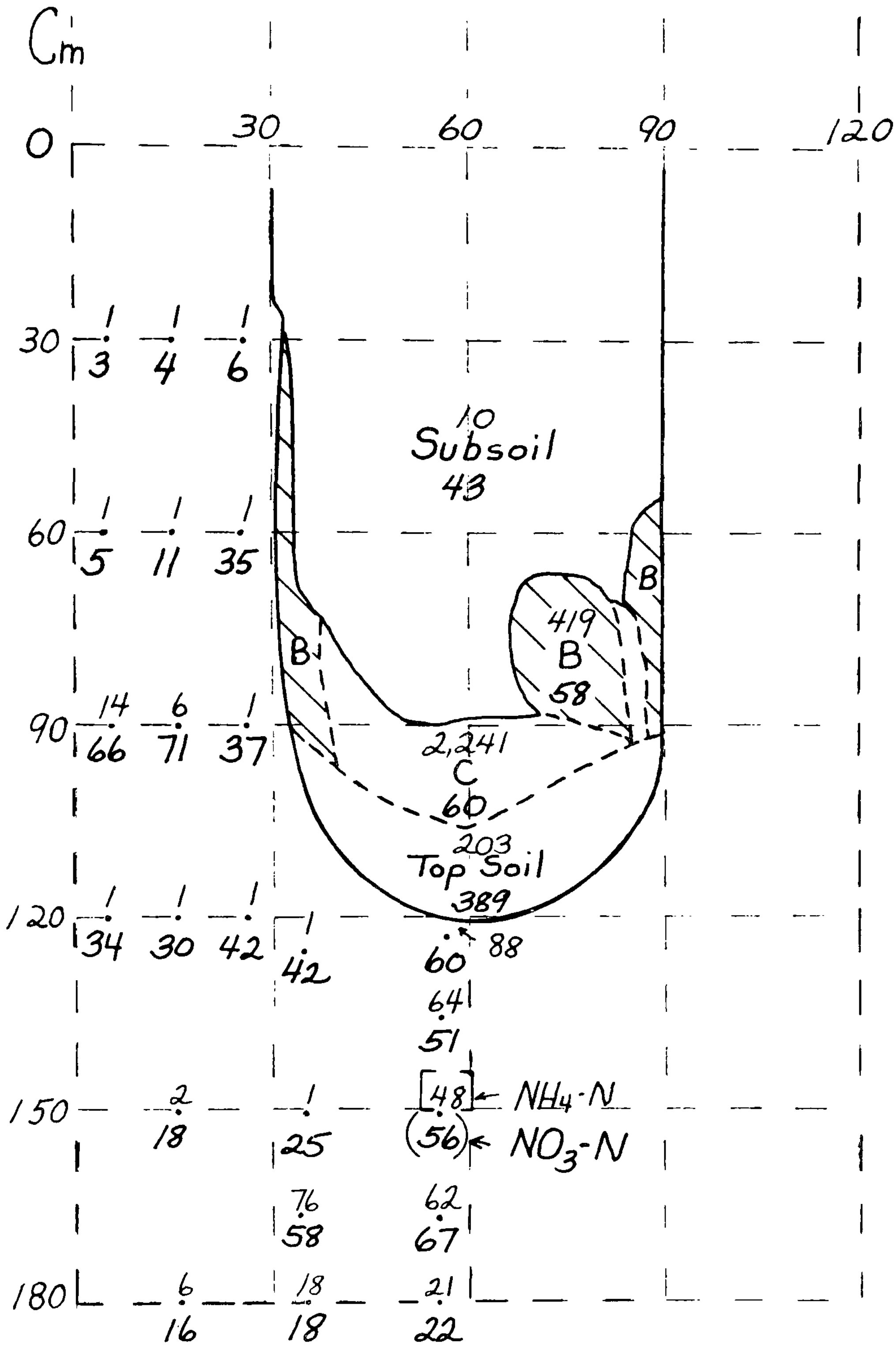
(C) Digested (Ia).

Figure 20 (continued). Ammonium- and nitrate-nitrogen in and around entrenched sludge 17 months after entrenchment.



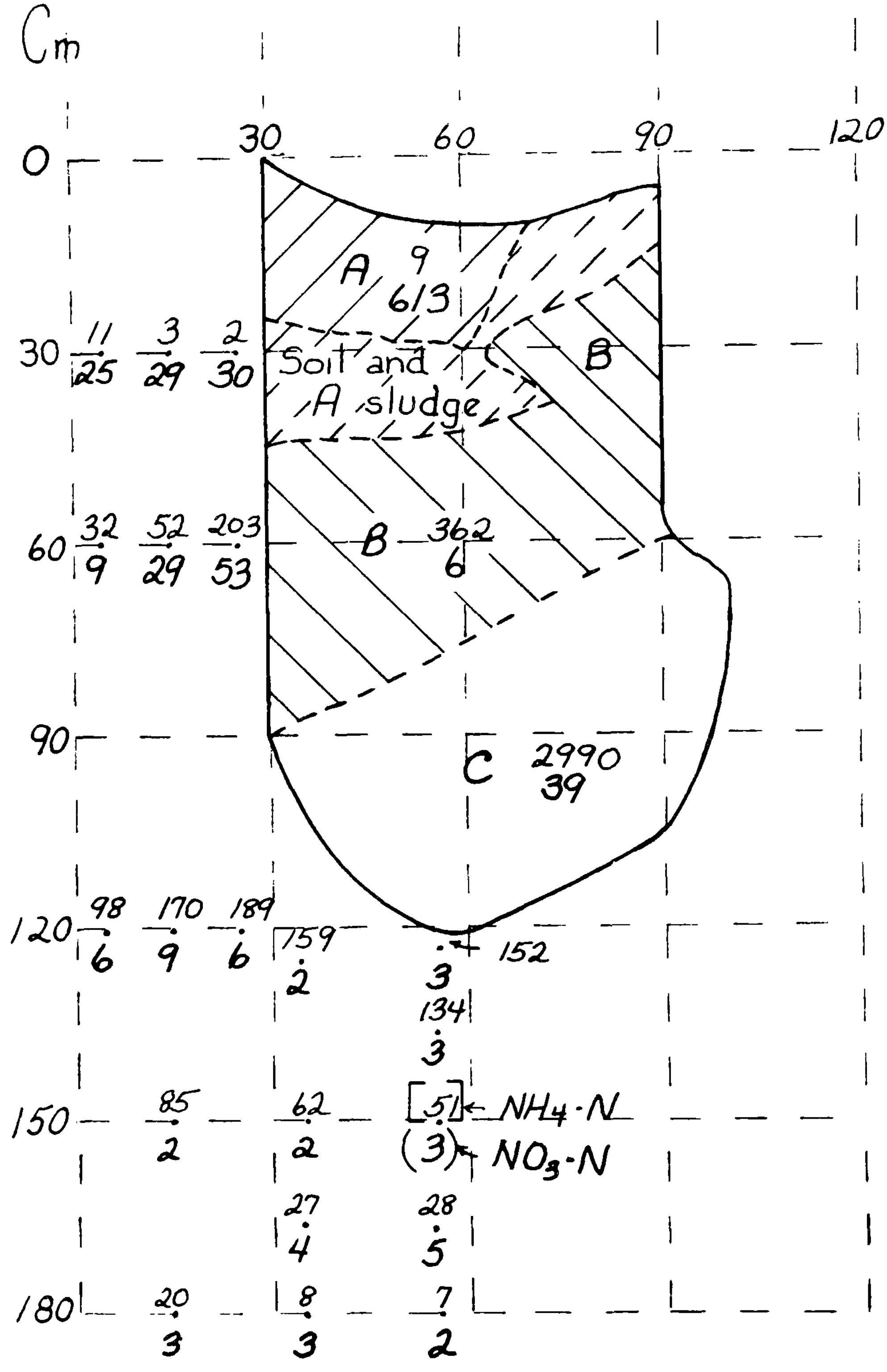
(D) Digested (Ia).

Figure 20 (continued). Ammonium- and nitrate-nitrogen in and around entrenched sludge 19 months after entrenchment.



(E) Raw-limed liquid (IVa).

Figure 20 (continued). Ammonium- and nitrate-nitrogen in and around entrenched sludge 19 months after entrenchment



(F) Digested (IIa).

Figure 20 (continued). Ammonium- and nitrate-nitrogen in and around entrenched sludge 17 months after entrenchment

Table 27. CHEMICAL OXYGEN, TOTAL NITROGEN, AND TOTAL CARBON IN SOIL SURROUNDING 60 x 60 cm DIGESTED (NO TOTAL C) AND RAW SLUDGE TRENCHES 17 MONTHS AFTER SLUDGE ENTRENCHMENT

Soil Location		Sludge				
		Digested 10/17/73		Raw 10/30/73		
		COD*	Total N	COD	Total N	Total C
		µg/g dry weight				%
Above sludge, cm						
15	55,15	396	262	375	286	2.2
Below, cm						
2	55,62**	442	286	688	696	1.7
15	55,75	259	171	1,143	210	-
30	55,90	564	110	312	91	0.04
60	55,120	381	110	250	8	0.04
Side, cm						
5	25,35	168	179	259	379	0.9
25	5,35	488	112	344	268	1.2

* COD on 1 to 1 water extraction of soil.

** Exact location key in Figure 19.

entrenched digested and raw-limed sludge might occur for periods in excess of a year. Salmonella survival fortunately was much less tenaceous. Positive identification did occur after 12 months in the digested 60 x 120 cm (2 x 4 foot) trench and after 19 months in the raw-limed liquid 60 x 120 cm trench.

Movement and Fate of Ammonium- and Nitrate-Nitrogen -- Data showing levels of nitrate- and ammonium-nitrogen in and around the trenches are presented in Table 26 and Figure 20A-F. Considerable movement of both nitrate- and ammonium-nitrogen occurred. Both of these forms of nitrogen were detected 60 cm (2 feet) below the trenches at concentrations considerably above the background levels in the control (Figure 20A).

The greatest concentrations of nitrate and ammonium were detected under the 60 x 60 cm digested and 60 x 120 cm raw-limed liquid trenches. As might be expected, vertical movement was greater than lateral movement.

Apparently the least nitrate moved under the 60 x 120 cm entrenched digested sludge. Also, little nitrate moved 30 to 60 cm (1 to 2 feet) below the 60 x 60 cm raw-limed entrenched sludge. Considerable concentrations occurred below the 60 x 60 cm digested entrenched sludge.

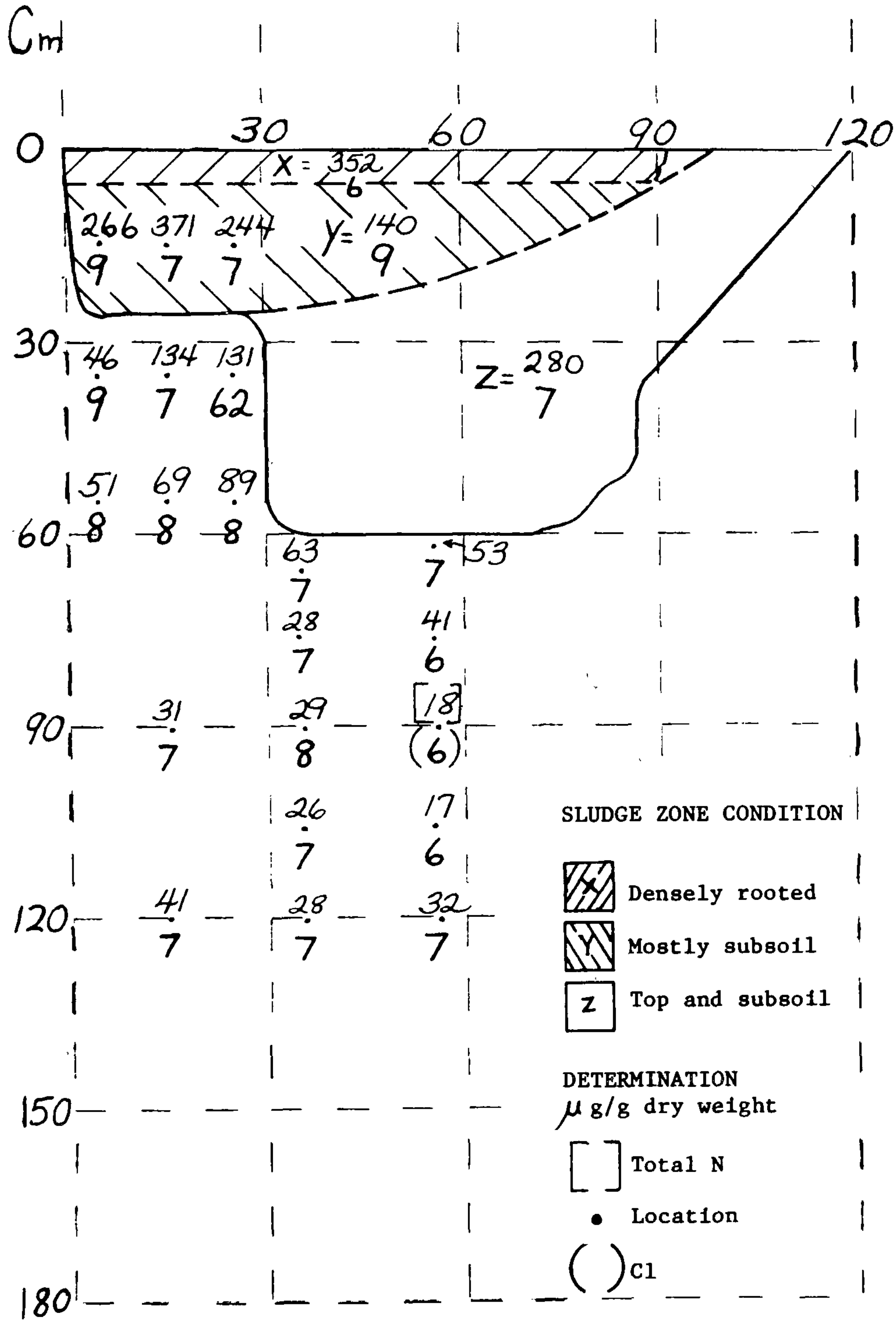
The concentrations of nitrate in the entrenched sludge increased with time as the sludge dewatered and became more aerobic (Table 26). In general, the concentrations of nitrate in the soil immediately below the entrenched sludge were greatest when concentrations of nitrate were greatest in the entrenched sludge above. As just described, however, concentrations of nitrate 30 to 60 cm below the trenches apparently depended more upon conditions below the trenches favorable to denitrification than upon sludge levels of nitrate.

Possibilities for Denitrification -- Conditions probably existed such that considerable loss of nitrate occurred by denitrification. Measurements of total nitrogen levels below and around the trenches when compared with the control indicate indirectly that organic materials were present which had moved out of the sludge (Table 27 and Figure 21A-F). Organic carbon and COD measurements made on a few samples from below the trenches also tended to support the contention that an organic energy source utilizable by denitrifying bacteria moved out of the entrenched sludge (Table 27). The results of detailed greenhouse trench simulation studies also show that considerable organic materials move out of the trenches (described in Section VI).

Gas measurements in, around, and below the trenches furthermore revealed near depletion of oxygen below the trenches (Figures 22, 23, and 24). Concentrations of oxygen began to increase below the raw and digested 60 x 60 cm trench treatments sooner than under the digested 60 x 120 cm trenched sludge.

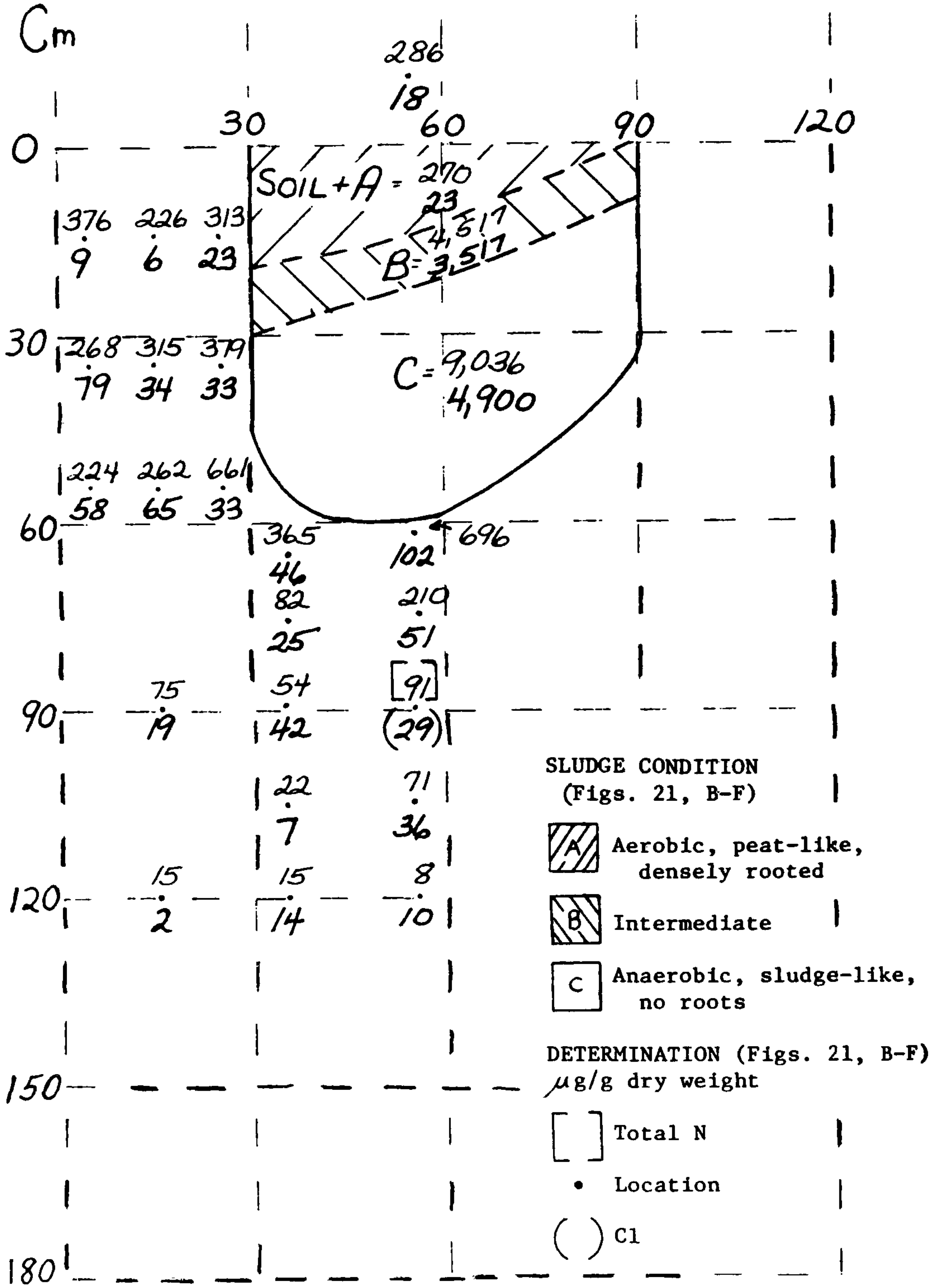
Possible Significance of Nitrogen Results -- The elevated levels of nitrate and ammonium found at considerable distances below the entrenched sludges suggested that these materials moved from the sludge through the soil to cause the increased ammonium and nitrate levels in the water in the drain line. The concentrations in the drainage water did not exceed drinking water standards, but increased with time. Nitrate concentrations may increase further as the entrenched sludge dewaters and becomes aerobic. Once aerobic, nitrification is supported and denitrification is depressed. During the study, the nitrogen from the entrenched sludge was not detected in the well water. The fate of nitrogen in the entrenched sludge studies should continue to be followed.

Movement of Chloride -- Chloride remaining in sludge and the surrounding soil from 17 to 19 months after entrenchment is shown in Figure 21F.



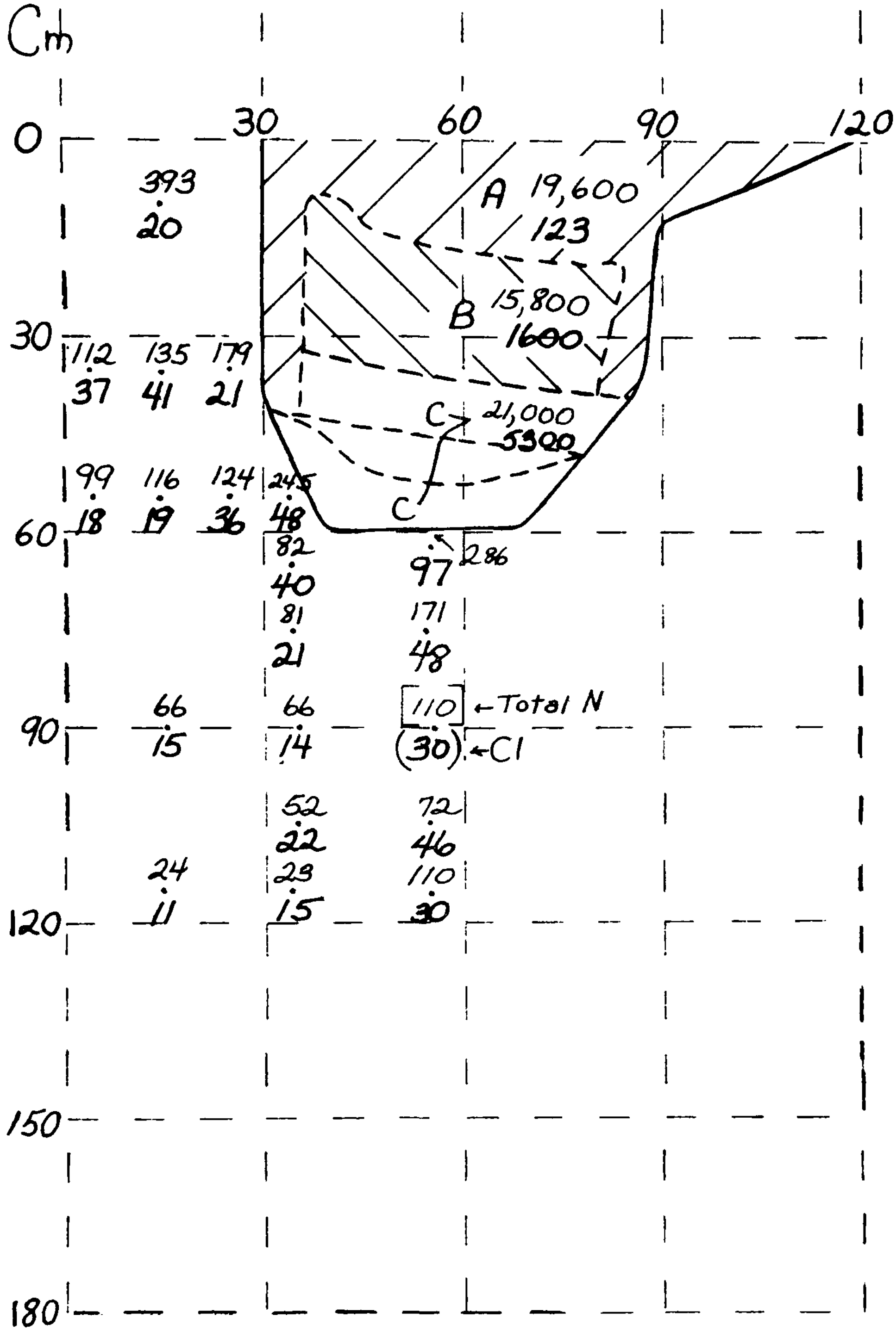
(A) Control (Ia).

Figure 21. Total nitrogen and chloride in and around entrenched sludge 17 months after entrenchment.



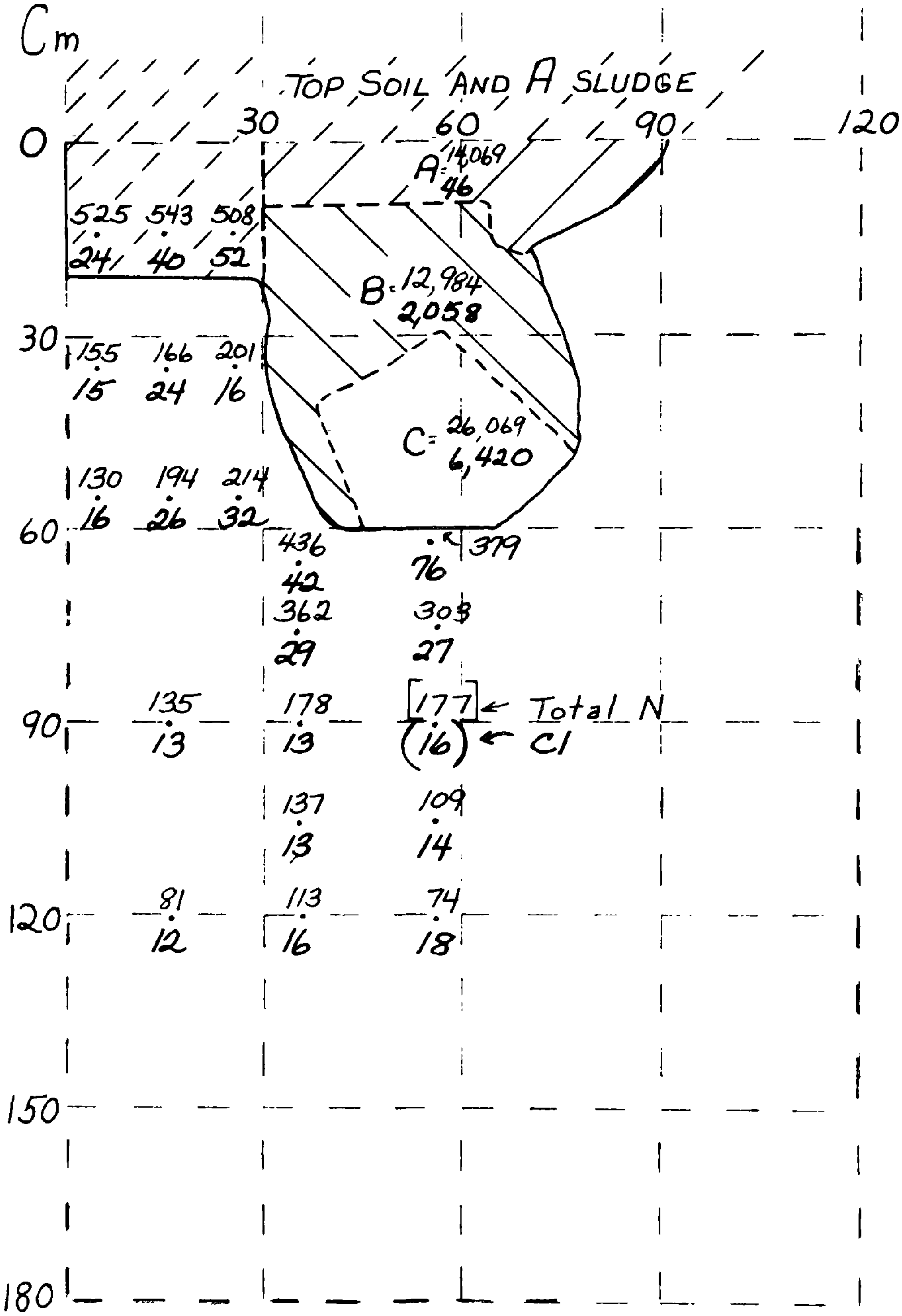
(B) Raw-limed (IIIa).

Figure 21 (continued). Total nitrogen and chloride in and around entrenched sludge 17 months after entrenchment.



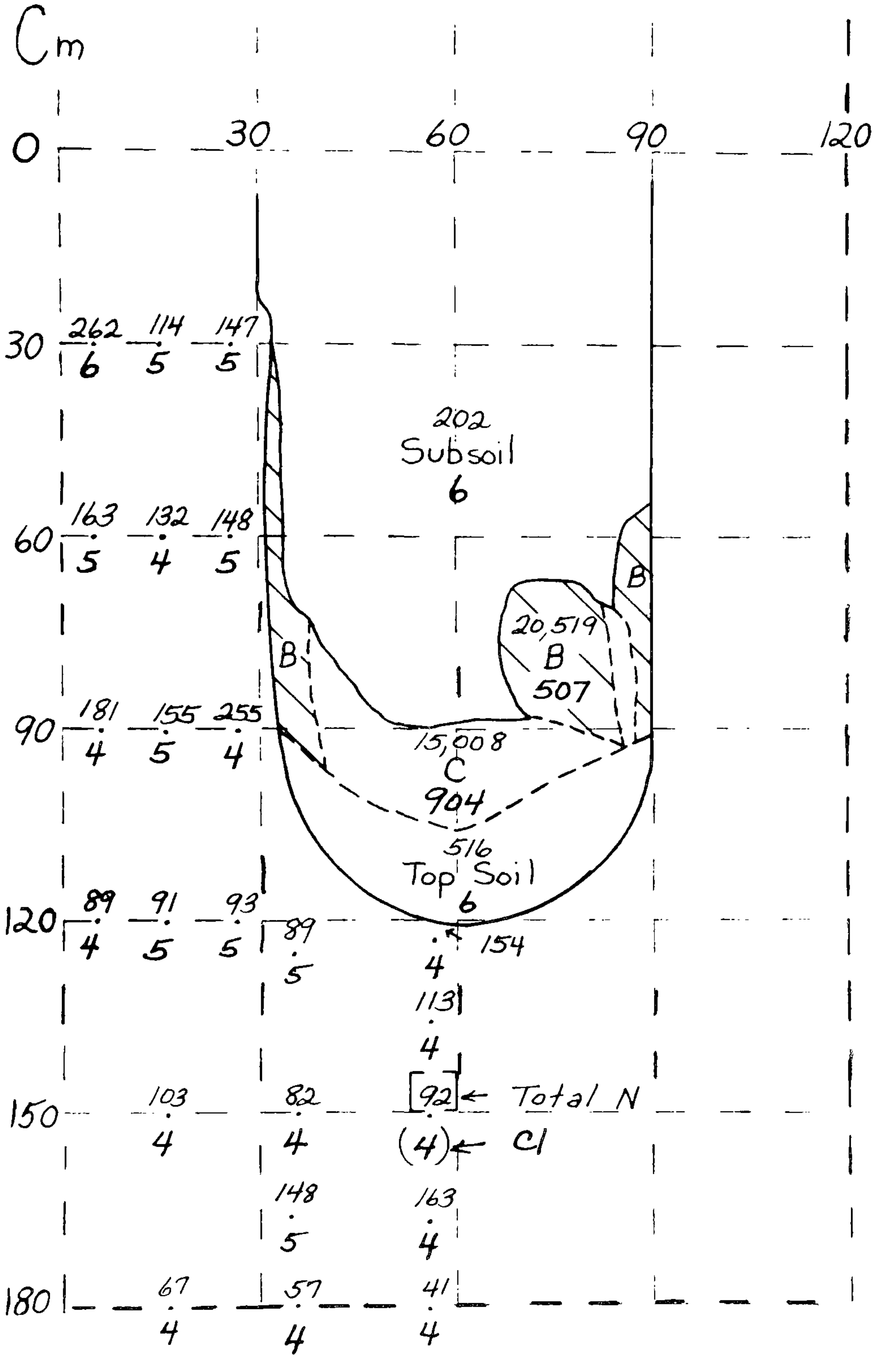
(C) Digested (Ia).

Figure 21 (continued). Total nitrogen and chloride in and around entrenched sludge 17 months after entrenchment.



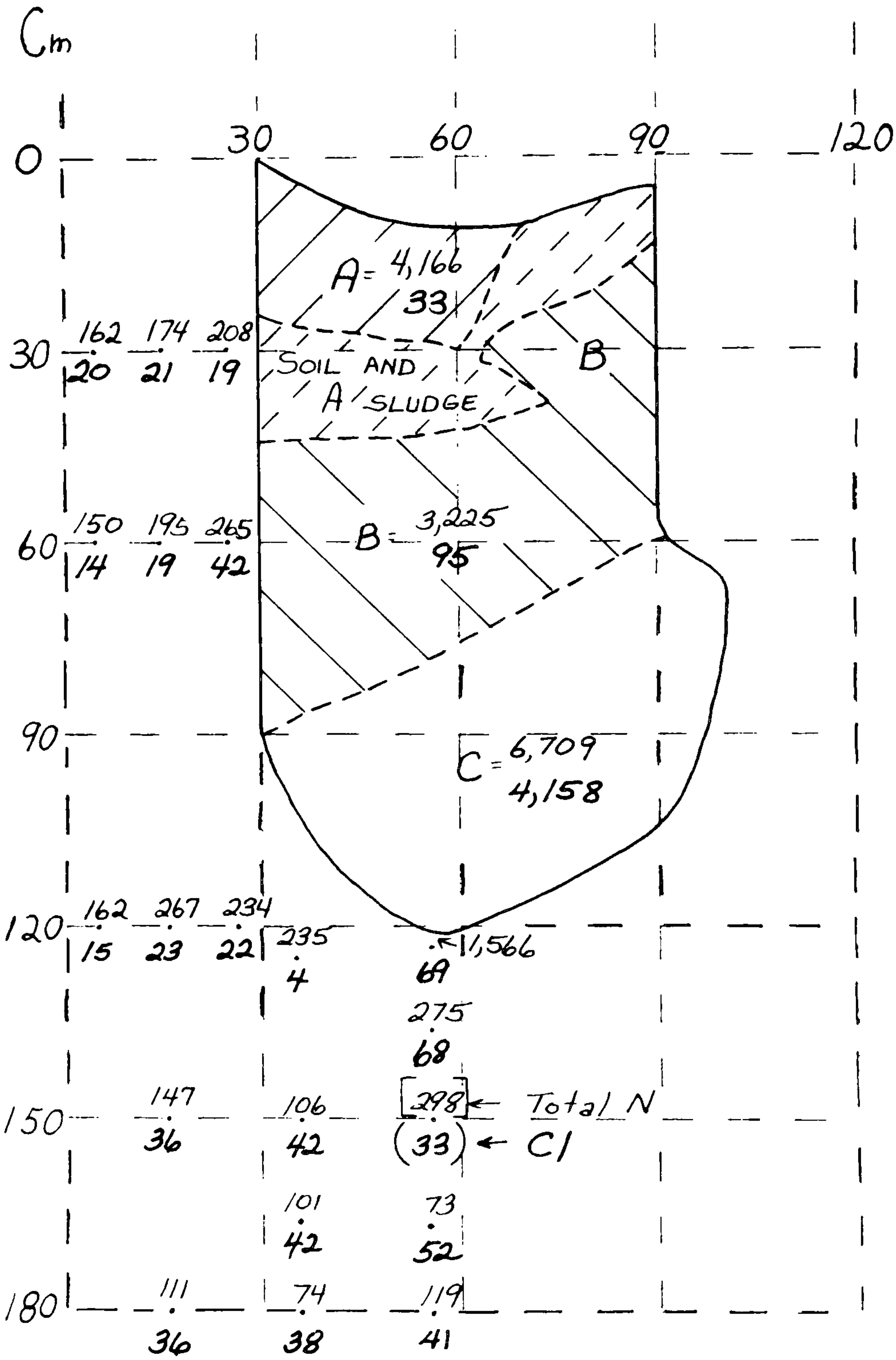
(D) Digested (Ia).

Figure 21 (continued). Total nitrogen and chloride in and around entrenched sludge 17 months after entrenchment.



(E) Raw-limed liquid (IVa).

Figure 21 (continued). Total nitrogen and chloride in and around entrenched sludge 19 months after entrenchment.



(F) Digested (IIa).

Figure 21 (continued). Total nitrogen and chloride in and around entrenched sludge 17 months after entrenchment.

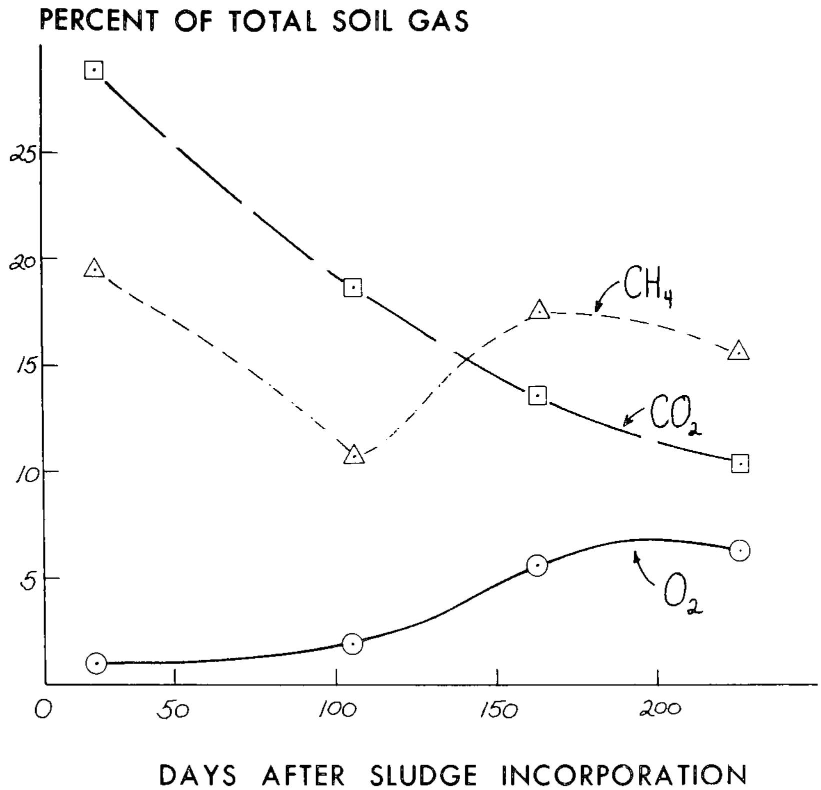


Figure 22. Levels of methane, carbon dioxide, and oxygen (15 cm) below digested sludge in 60 x 60 cm trench with time after entrenchment.

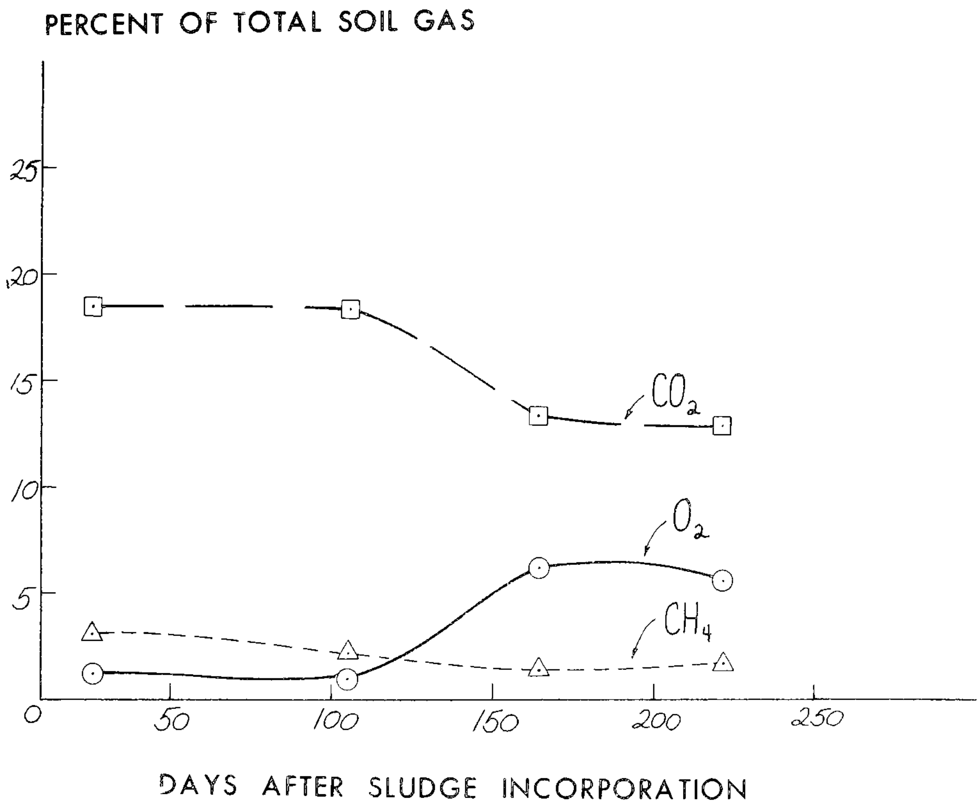


Figure 23. Levels of methane, carbon dioxide, and oxygen (15 cm) below raw-limed sludge in 60 x 60 cm trench with time after entrenchment.

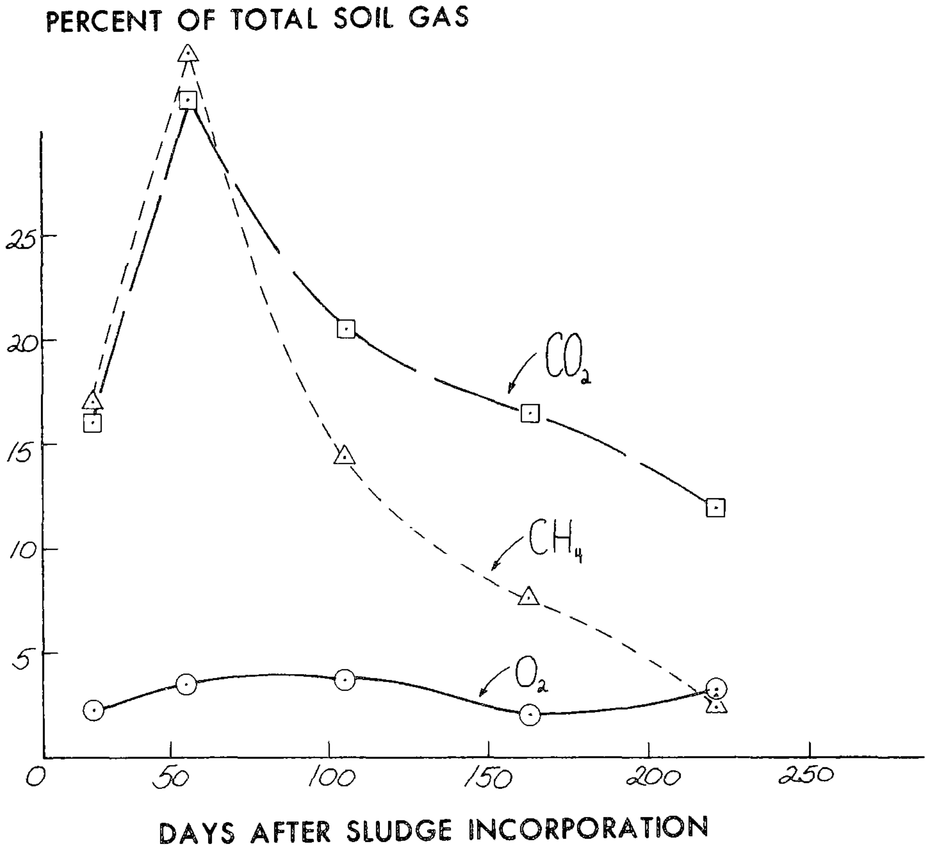


Figure 24. Levels of methane, carbon dioxide, and oxygen (15 cm) below digested sludge in 60 x 120 cm trench with time after entrenchment.

Chloride moved greater distances than nitrate and ammonium (Figure 21A to F vs 20A to F). Chloride movement was greatest where initial chloride levels in the sludge were greatest, as contrasted to the case for nitrate movement where denitrification modified the relationship. Chloride movement seemed sufficient to have caused the somewhat elevated levels of chloride in the drainage water and in underground well water.

Movement of Heavy Metals -- There has been no detectable movement of heavy metals greater than 2.5 cm (1 inch) below the trenches (Tables 28 and 29 and Figures 25A to D). There was, however, apparently a lateral movement of metals into the soil between the trenches of digested sludge 17 to 19 months after entrenchment. There was no detectable lateral movement 10 months after sludge entrenchment.

The reason for this lateral movement is unclear. Perhaps the higher organic levels in the surface soil to the side compared with the subsurface soil below coupled with the lack of lime in the entrenched digested sludge may have contributed to metal movement. Also, the digested unlimed sludge on the side of the trench may have dewatered more than the sludge on the bottom. Additional research (Appendix) has also shown small amounts of metal movement downward into the soil out of entrenched sludge. Movement is related to an aerobic sludge state, presence of nitrate-N, lowered pH, and absence of lime.

Changes in Sludge Physical Properties -- Entrenched sludge dewatered with time. The dewatering was greatly enhanced by penetration of growing plant roots. By August 1973 three distinct zones were observed in the 60 x 60 cm digested entrenched sludge. The first zone was located around the edge of the trench to a depth of about 30 cm (12 inches) and 7.5 to 15 cm (3 to 6 inches) down from the top (Zone A, Figure 26). Sludge Zone A was densely rooted, gray in color and dry and peat-like. The zone was very porous and aerobic and water could easily percolate through. A similar change in sludge properties occurred with root penetration in digested sludge in the greenhouse trench simulation studies (Section VI).

The third zone consisted of approximately the bottom half of the entrenched sludge (Zone C, Figure 26). Sludge Zone C was essentially devoid of roots, very dense, black in color, and moist, and appeared to be physically unchanged from the time it was placed in the trench. There was little, if any, water percolation through this anaerobic sludge. A similar Zone C was observed in the greenhouse trench simulation studies.

The second zone (Zone B, Figure 26) was the zone between Zones A and C Sludge Zone B contained fewer roots than Zone A and was gray-brown in color. It was considerably drier than Zone C but not as dry as Zone A. It was moist and peat-like, was essentially aerobic, and allowed some water percolation.

The water contents of the different zones in October and November 1973 are given in Table 30. The mean water contents of the digested sludges

Table 28. EXTRACTABLE ZINC IN AND AROUND DIGESTED AND RAW-LIMED ENTRENCHED SLUDGE WITH TIME

Determination		DTPA-TEA extractable zinc μg/g dry weight						
Sludge type		Raw, 60 x 60 cm		Digested, 60 x 60 cm		Digested, 60 x 120 cm		Control
Months after entrenchment		7	17	17	19		7	18
Trenched sludge			(A)* -	(A) 1060	821	55,55	582	(X)** 1.67
			(B) 313	(B) 1065	1156			(Y) <0.1
			(C) 215	(C) 490	1102			(Z) 0.54
Below, cm								
2	55,62+	0.4	0.52	0.82	<0.1	55,122	0.3	<0.1
15	55,75	0.4	0.12	0.16	<0.1	55,135	0.2	<0.1
30	55,90	0.3	0.16	0.10	<0.1	55,150	0.2	<0.1
45	55,105	0.3	-	-	<0.1	-	-	<0.1
60	55,120	0.3	0.10	0.16	<0.1	55,180	0.2	<0.1
Side, cm								
5	25,35	0.4	0.16	6.72	4.1	25,55	0.2	-
15	15,35	0.6	-	2.20	9.0	15,55	0.3	<0.1
25	5,35	0.4	0.06	0.20	4.3	5,55	0.2	<0.1
Above		-	0.38	0.36	-		1.3	-

* Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration.

** Region X was the top 5 cm of the trenched control, region Y was the next 20 cm of the control trench, and region Z was the bottom 35 cm of the control trench.

\+ These locations are given in Figure 19.

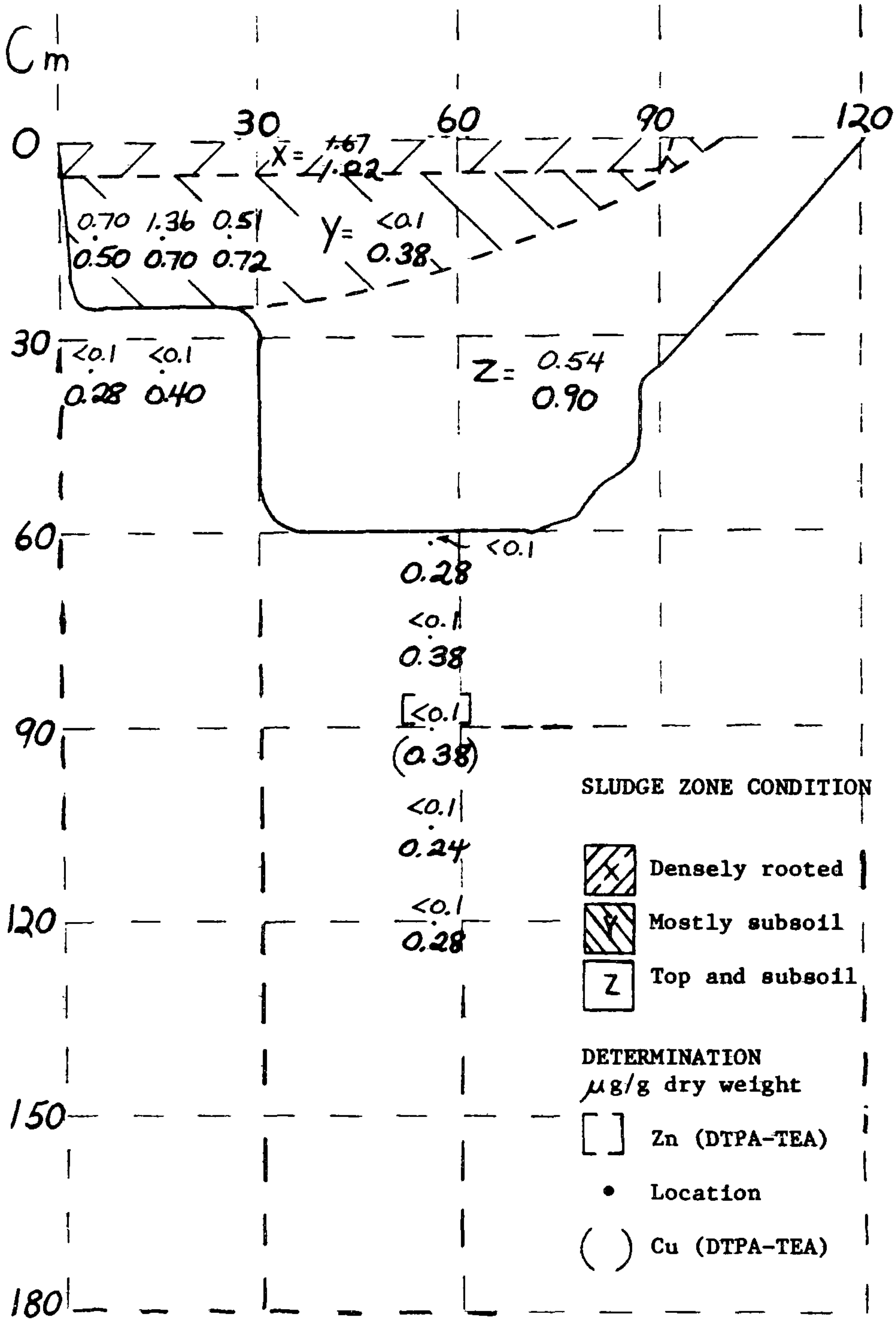
Table 29. EXTRACTABLE COPPER IN AND AROUND DIGESTED AND RAW-LIMED ENTRENCHED SLUDGE WITH TIME

Determination		DTPA -TEA extractable copper µg/g dry weight								
Sludge type		Raw, 60 x 60 cm		Digested, 60 x 60 cm			Digested, 60 x 120 cm		Control	
Months after entrenchment		7	17		17	19		7		18
Trenched sludge		(A)*	-	(A)	365	352	55,55	74	(X)**	1.02
		(B)	113	(B)	280	239			(Y)	0.38
		(C)	58	(C)	22	130			(Z)	0.90
Below, cm										
2	55,62+		0.54		0.44	0.44	55,122	0.5		0.28
15	55,75		0.34		0.40	0.23	55,135	0.4		0.38
30	55,90		0.32		0.34	0.39	55,150	0.3		0.38
45	55,105		-		-	0.23	-			0.24
60	55,120		0.30		0.36	0.22	55,180	0.6		0.28
Side, cm										
5	25,35		0.64		0.54	0.33	25,55	0.4		-
15	15,35		-		0.36	0.31	15,55	0.4		0.40
25	5,35		0.36		0.42	0.28	5,55	0.3		0.28
Above			0.46		0.52	-		0.7		

* Regions A, B, and C represent different degrees of sludge decomposition in the trenches shown in Figure 26 and are: (A) peat-like dry, considerable root penetration; (B) peat-like, moist, some root penetration; and (C) original moist condition, little root penetration.

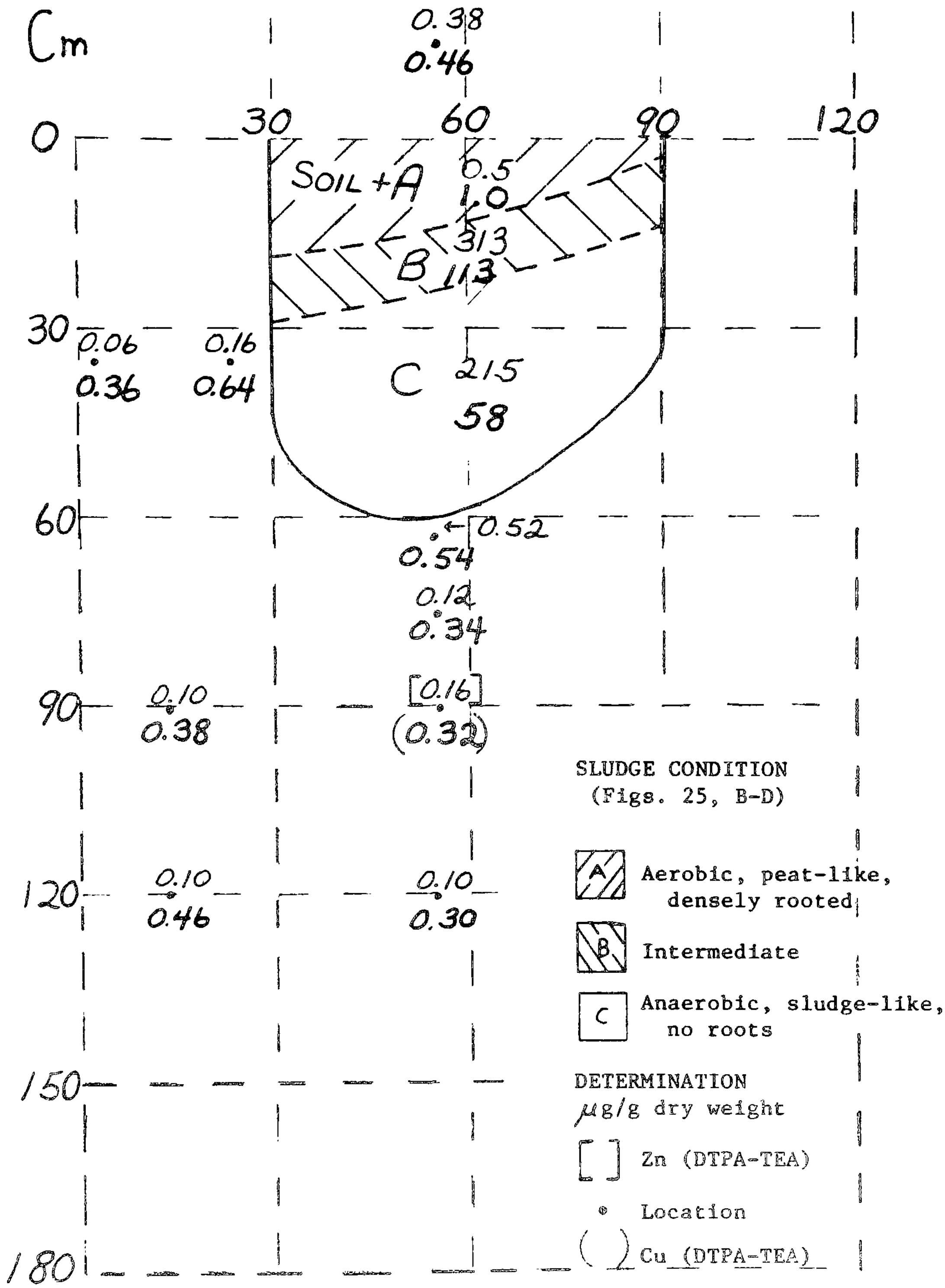
** Region X was the top 5 cm of the trenched control, region Y was the next 20 cm of the control trench, and region Z was the bottom 35 cm of the control trench.

\+ These locations are given in Figure 19.



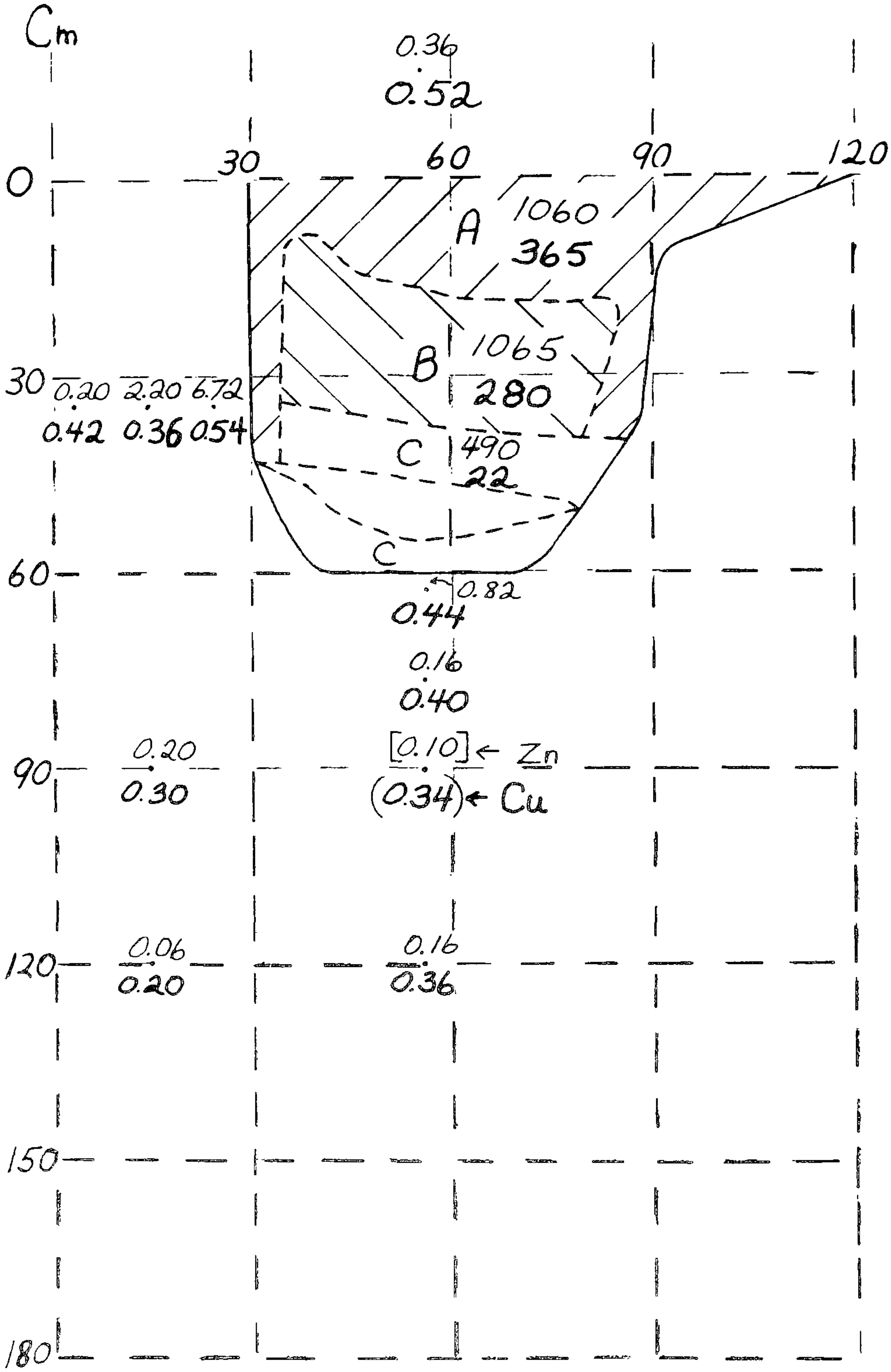
(A) Control (Va).

Figure 25. Extractable zinc and copper in and around entrenched sludge 18 months after entrenchment.



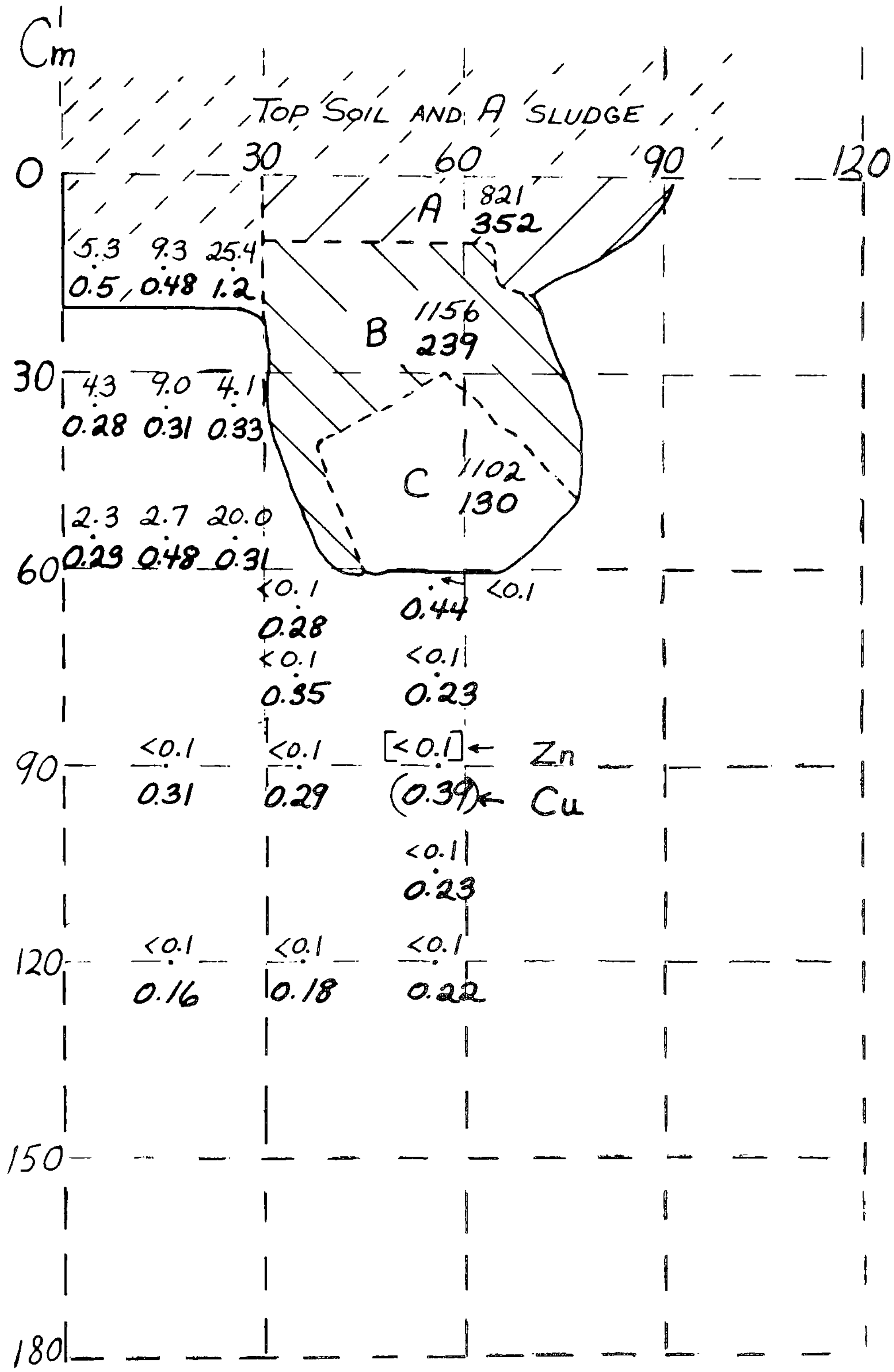
(B) Raw-limed (IIIa).

Figure 25 (continued). Extractable zinc and copper in and around entrenched sludge 17 months after entrenchment.



(C) Digested (Ia).

Figure 25 (continued). Extractable zinc and copper in and around entrenched sludge 17 months after entrenchment.



(D) Digested (Ia).

Figure 25 (continued). Extractable zinc and copper in and around entrenched sludge 19 months after entrenchment.

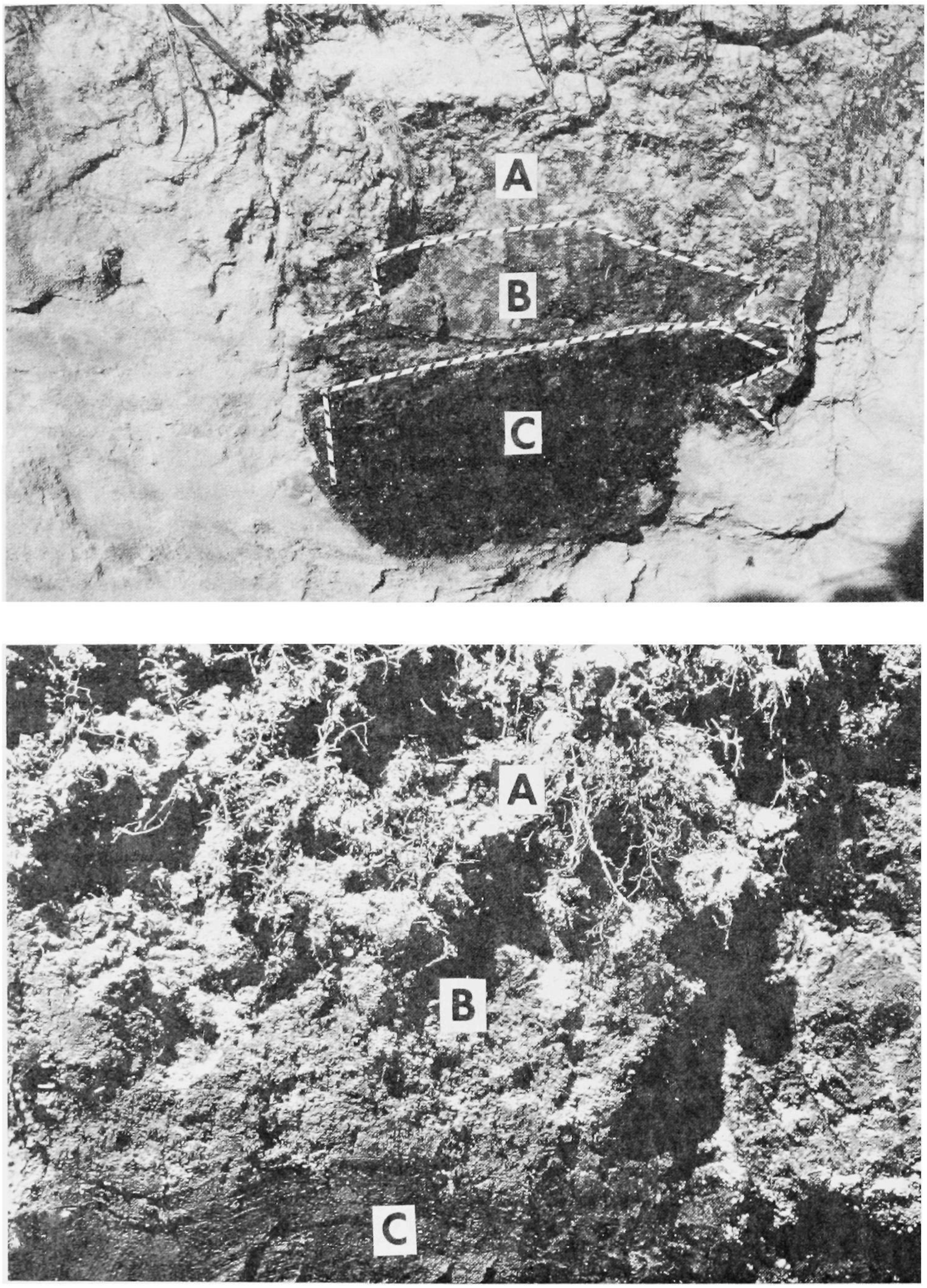


Figure 26. Cross-sectional excavation of entrenched digested sludge after 17 months (Oct. 17, 1973) showing degree of weathering. Zone A = weathered, densely rooted, peat-like, aerobic. Zone B= weathered , sparsely rooted, moist peat-like, aerobic. Zone C = unweathered, anaerobic.

Table 30. WATER CONTENT* OF SLUDGES AFTER ENTRENCHMENT

Sludge zone **	Water content+ in sludge treatment++					
	Ia 17*+	Ia 18	IIIa 17	IIa 18	Ia, IIa 19	V 18
A	25	36	9	18	28	6
B	53	59	18	21	50	6
C	64	67	66	58	53	7

* The principal water content of sludges was from 73-82% in May and June 1972 (Table 4).

** Zone A = dry, peat-like; B = moist, peat-like; C = original appearance.

\+ Water percentages determined by England Laboratories, Beltsville, Maryland.

++ Key to treatment symbols given in Table 2.

*+ Months after entrenchment.

at time of entrenchment was 73% and for the raw-limed sludge 82%. Note the considerable decrease in water content caused by root penetration and plant growth in Zone A and somewhat lower decrease in Zone B. The water content of sludge, Zone C, decreased by only about 9% from 73 to 64 percent without root penetration after 17 months in the trenches.

We do not know exactly how the sludge would have dewatered in the field without root penetration. However, in the 60 x 120 cm entrenched sludge area in an observation pit dug in November 1973 (Figure 20F) there was a large zone below the A zone where the appearance of the sludge changed from black to brown and the water content decreased. Few, if any, roots occurred in this zone. Therefore gradual dewatering and change to a more aerobic state occurred with or without penetration of plant roots. Insects and microorganisms must have had some effect on the dewatering. In any event, the speed and perhaps the extent of drying was reduced in sludge where root penetration did not occur.

Table 31. CHEMICAL CHARACTERISTICS OF RAW-LIMED SLUDGE (60 x 60 cm) AS INFLUENCED BY DECOMPOSING (17 MONTHS AFTER ENTRENCHMENT

Determination	Units*	B**	C+
Raw-limed, 17 months, 10/30/73, IIIa			
Total Zn++	μg/g	-	463
Extractable Zn*+	μg/g	313	215
% Extractable Zn	%	-	46
Total Cu	μg/g	150	238
Extractable Cu	μg/g	113	58
% Extractable Cu	%	75	24
pH wet		6.4	7.4
pH dry		-	-
Water content	%	53	64
NH_4-N	μg/g	27.8	2,523
NO_3-N	μg/g	1,871	105.7
Total N	μg/g	4,517	9,036
Cl	μg/g	3,517	4,900

* μg/g calculated on a dry weight basis.

** Sludge, moist, peat-like aerobic.

\+ Sludge, anaerobic.

++ Dry ashed, taken up in HCl.

*+ 5mM DTPA, 10mM $CaCl_2$, 100mM TEA, Lindsay and Norvell method (1 g sludge/50 ml solution).

The different sludge zones were observed to different degrees in all observation pits dug in all entrenched sludge treatments. Diagrams of their size and arrangement are shown in Figure 20 A to F.

Changes in Sludge Chemical Properties -- Nitrogen - The dewatering of both raw and digested entrenched sludge, and the resulting increase in aerobic conditions favored the conversion of ammonium to nitrate (Figure 20A to F and Tables 31 to 34). The concentrations of total nitrogen were generally high in each sludge zone (Figure 20A to F and Tables 31 to 34). Sufficient samples were not taken to determine if there was any pattern of overall change in total nitrogen with dewatering.

Table 32. CHEMICAL CHARACTERISTICS OF DIGESTED SLUDGE (60 x 60 cm) AS INFLUENCED BY EXTENT OF DECOMPOSITION (17 MONTHS AFTER ENTRENCHMENT)

Determination	Units*	A**	B+	C++
Digested, 17 months, 10/17/73, Ia				
Total Zn*+	μg/g	1,850	1,913	1,620
Extractable Zn+*	μg/g	1,060	1,065	490
% Extractable Zn	%	57	56	30
Total Cu	μg/g	775	1,690	668
Extractable Cu	μg/g	365	280	22
% Extractable Cu	%	47	17	3
pH wet		6.9	4.8	6.9
pH dry		-	-	-
Water content	%	9	18	66
NH_4-N	μg/g	331	439	4,392
NO_3-N	μg/g	1,222	1,130	42
Total N	μg/g	19,567	15,810	20,983
Cl	μg/g	123	1,600	5,300

* μg/g calculated on a dry weight basis.
** Sludge, densely rooted, peat-like, aerobic.
+ Sludge, moist peat-like, aerobic
++ Sludge, anaerobic.
*+ Dry ashed, taken up in HCl.
+* 5mM DTPA, 10mM $CaCl_2$, 100mM TEA, Lindsay and Norvell method (1 g sludge/50 ml solution).

Chlorides - Chlorides were lowest in the most dewatered sludge (Zone A) and highest in the least dewatered (Zone C). The chloride distribution was most likely caused by chloride leaching from the more porous weathered sludges into the soil (Tables 31 to 34 and Figure 21A to F).

Metals - As the entrenched sludge dewatered, a relative increase in DTPA-TEA extractable metal concentrations, particularly copper, occurred (Tables 31 to 34 and Figure 25A to D). Extractable copper in digested sludge of aerobic Zone A was 3 to 15 times higher than that of anaerobic Zone C. Extractable zinc in some trenches did not vary with sludge

Table 33. CHEMICAL CHARACTERISTICS OF DIGESTED SLUDGE (60 x 60 cm) AS INFLUENCED BY EXTENT OF DECOMPOSITION (19 MONTHS AFTER ENTRENCHMENT

Determination	Units*	A**	B+	C++
Digested, 19 months, 11/27/73, Ia				
Total Zn*+	μg/g	1,764	2,424	2,387
Extractable Zn+*	μg/g	821	1,156	1,102
% Extractable Zn	%	47	48	46
Total Cu	μg/g	797	1,036	968
Extractable Cu	μg/g	352	239	130
% Extractable Cu	%	44	23	13
pH wet		4.3	5.4	6.8
pH dry		5.1	5.4	6.8
Water content	%	36	59	67
NH_4-N	μg/g	65	558	3,965
NO_3-N	μg/g	950	1,007	57
Total N	μg/g	14,069	12,984	26,069
Cl	μg/g	46	2,058	6,420

* μg/g calculated on a dry weight basis.
** Sludge, densely rooted, peat-like, aerobic.
\+ Sludge, moist peat-like, aerobic
++ Sludge, anaerobic.
*+ Dry ashed, taken up in HCl.
+* 5mM DTPA, 10mM $CaCl_2$, 100mM TEA, Lindsay and Norvell method (1 g sludge/50 ml solution).

dewatering and in others varied twofold. Extractable cadmium and nickel (Table 34) both varied several fold with the greatest increase in the most dewatered aerobic sludge. In most instances the total metal levels were not appreciably different.

The reason for the increase in DTPA-TEA extractable metals is unclear. Some of the increase was attributed to changes in pH with dewatering. The 8-fold increase in extractable copper, which is far too great to be explained by changes in pH, may in part be explained by the presence of metal sulfide compounds in anaerobic sludge and not in the dewatered aerobic sludge. Sludge was removed (Table 34) from various zones in the

Table 34. CHEMICAL CHARACTERISTICS OF DIGESTED SLUDGE AS INFLUENCED BY EXTENT OF DECOMPOSITION (19 MONTHS AFTER ENTRENCHMENT)

Determination	Units*	A**	B+	C++
Zones taken from different locations in plots Ia and IIa, digested sludge for metal uptake experiment.				
Total Zn*+	µg/g	1,336	1,760	1,027
Extractable Zn+*	µg/g	532	785	305
% Extractable Zn	%	40	45	30
Total Cu	µg/g	483	582	366
Extractable Cu	µg/g	217	218	26
% Extractable Cu	%	45	37	7
Total Ni	µg/g	58.2	91.0	111.3
Extractable Ni	µg/g	7.3	8.6	7.5
% Extractable Ni	%	13	9	7
Total Cd	µg/g	14.8	21.2	10.1
Extractable Cd	µg/g	6.0	9.6	1.0
% Extractable Cd	%	41	45	10
pH wet		5.2	5.5	8.0
pH dry		5.8	5.9	6.8
Water content	%	28	50	53
NH_4-N	µg/g	266	690	2,742
NO_3-N	µg/g	2,409	3,905	32
Total N	µg/g	19,185	10,715	16,476
Cl	µg/g	145	1,081	2,756

* µg/g calculated on a dry weight basis.

** Sludge, densely rooted, peat-like aerobic.

\+ Sludge, moist peat-like, aerobic.

++ Sludge, anaerobic.

*+ Dry-ashed, taken up in HCl.

+* 5mM DTPA, 10mM $CaCl_2$, 100mM TEA, Lindsay and Norvell method (1 g sludge/50 ml solution).

field and brought into the greenhouse to determine if differences in extractable metals would be reflected in metals absorbed by corn, beans, or chard. The experiment was not completed at the time of writing this report.

Plant Response

Sweet Corn 1972 -- Two varieties of sweet corn were planted on the plots in rows traverse to the direction of sludge entrenchment in 1972 as shown in Figure 14. The most vigorous growth of sweet corn, both silver queen and Iowa chief, occurred on the digested 60 x 60 cm plots (Figure 27A). Little difference was observed on growth of corn on the disked or disked and ripped plots.

The second best plant response occurred on the raw-limed 60 x 60 cm plots (Figure 27B). In this case growth of corn on the disked and ripped plots was better than growth on the disked only plots. The third poorest growth occurred on the digested 60 x 120 cm plots (Figure 27C) and the raw-limed liquid 60 x 120 cm plots (Figure 27D). There was little benefit or detriment from ripping in addition to disking the digested 60 x 120 cm plots. Ripping was not performed in the raw-limed liquid plots.

Growth of corn was better on the digested than on the raw-limed 60 x 60 cm entrenched sludge plots because of the greater initial toxic effects of the raw-limed sludge on plant growth. The toxic effects probably were caused by low oxygen and the presence of ammonia and toxic volatiles. The ammonia resulted from the alkaline pH of the raw-limed sludge and the volatiles from anaerobiosis produced by the readily decomposable organic materials and the wet conditions. Greenhouse and laboratory studies have shown that low oxygen, ammonia, and volatiles can inhibit root growth. The responsible volatiles have not been identified.

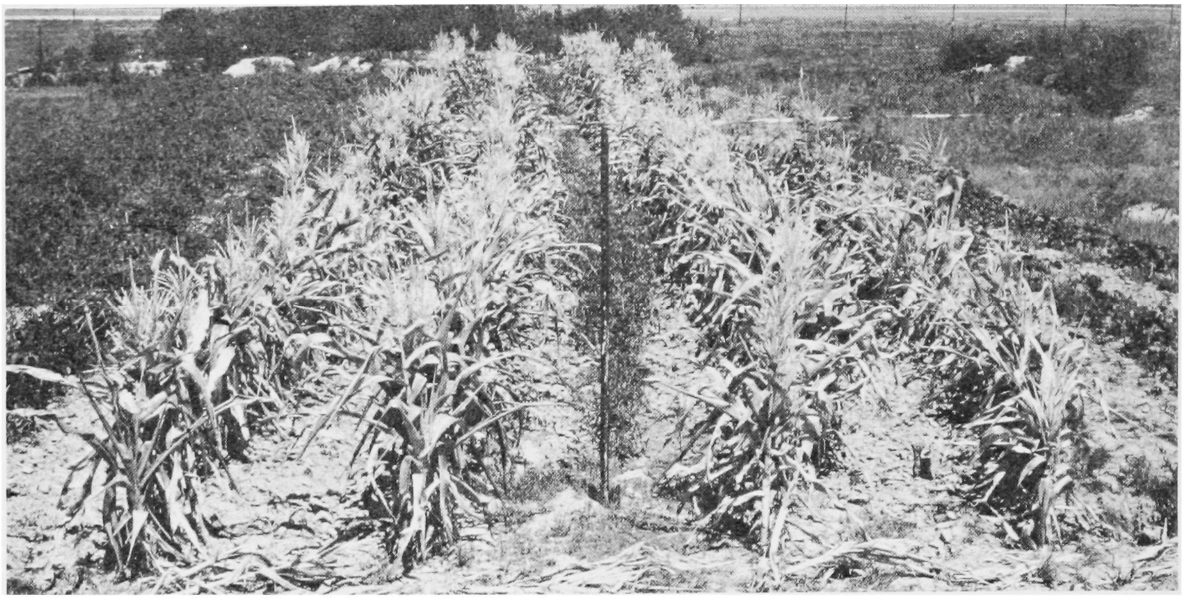
One might expect, therefore, that ripping (mixing and diluting) the raw-limed sludge into soil would hasten the decomposition and conversion of the sludge to a more stable form and shorten the period of initial toxicity. The decomposition should benefit crop growth. As previously stated, ripping did improve corn growth in the raw-limed entrenched treatment. Ripping did not show any benefit to crop growth with the more stable entrenched digested sludge.

A series of greenhouse trench simulation studies, which partly preceded and partly followed the field studies, showed that corn roots did not penetrate more than a few inches into raw-limed entrenched sludges during the 5-month period. On the other hand corn roots rather quickly penetrated digested sludge. In the greenhouse as in the field, corn growing in the digested sludge tests was better than in the raw-limed sludge tests.

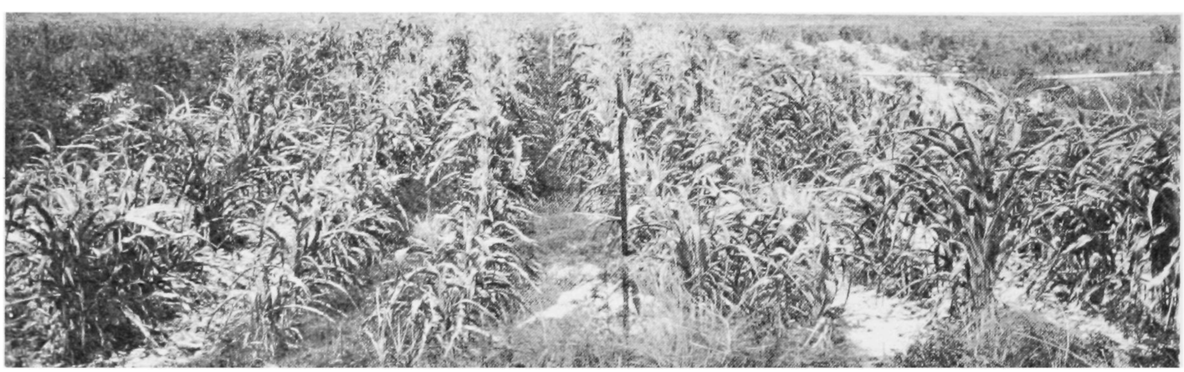
(A) Growth on 60 x 60 cm digested sludge disked plot Ia.

(B) Growth on 60 x 60 cm raw-limed sludge plot IIIa; left of pole -- corn on disked and ripped noticeably larger than corn on right of pole -- disked only.

Figure 27. Sweet corn growing on sludge plots, August 1972.



(C) Growth on 60 x 120 cm digested sludge plot IIa; left of pole -- corn on disked and ripped only slightly better if at all than corn on right of pole -- disked only.



(D) Growth on 60 x 120 cm raw-limed liquid sludge disked plot IVa.

Figure 27. Sweet corn growing on sludge plots, August 1972.

All corn growth was rather poor for several probable reasons. First, the soil was extremely sandy and the initial attempts at irrigating were inadequate because of the incomplete irrigation system originally available. Secondly, the surface 30 to 37 cm (12 to 15 inches) of soil covering the entrenched sludge was predominately a sandy subsoil low in plant nutrients. This subsoil received chemical phosphorus and potassium fertilization and lime, but little or no chemical nitrogen fertilizer was applied. The corn plants had to grow down about 12 cm before their roots penetrated the subsoil cover over the sludge to obtain sludge nitrogen. Growth was not as bad as it might have been because disking of the plots and spillage during entrenchment resulted in some sludge in the surface layers of soil. Thirdly, the corn suffered damage from wildlife which abounded on the entrenchment site.

Growth of corn on the digested and raw-limed 60 x 60 cm entrenched sludge treatments was better than on the digested and the raw-limed 60 x 120 cm treatments for at least two reasons: (1) there was closer spacing between the trenched sludge, and (2) a thinner cover of soil over the sludge.

Rye 1972-73 -- Little definitive data were recorded on the rye crop. Where spacing between trenches averaged 275 cm (9 feet) in the raw-limed 60 x 120 cm plots, the rye growth was very uneven (Figure 28). Where the trenches were 60 cm apart, little unevenness in growth response was observed.

Fescue Growth 1972-73 -- Not all crops suffer from initial toxicity to the same degree. Kentucky-31 tall fescue, for example, was more tolerant of the initial toxic effects of sludges than corn. Some of the best growth of fescue occurred in the raw-limed 60 x 60 cm trench plots. Fescue roots showed little penetration of raw or digested sludge in the field in 1972 (Figure 18B), but since fescue is a perennial crop with continued growth in 1973, extensive penetration of the top foot of the digested entrenched sludge occurred along with changing of sludge properties (Figures 18A and 26). Root penetration was also observed in the entrenched raw-limed sludge to a lesser degree.

The benefits of entrenched sludge on fescue growth can be seen even in December in a photograph of fescue growing on a control trench area where several trenches had been mistakenly filled with sludge (Figure 29). Note also the better growth on the digested sludge entrenched area to the right.

The concentration of heavy metals in tops of tall fescue is given in Table 35. These concentrations must be considered only as trends because of limited data. In attempting to understand the results consider first of all that zinc is readily absorbed and translocated to the tops of fescue, while nickel and copper are less readily absorbed and particularly less readilv translocated to fescue tops. Secondly, of the three elements, copper absorption is most readily enhanced when in association with a chelate. Chelates are most abundant in an anaerobic sludge and decrease as sludge dewaters and becomes aerobic. This may explain part of the decrease in copper and nickel uptake with time.

Figure 28. Rye growing on raw-limed liquid sludge plot IVa in May 1973. Note the pronounced greater vigor of rye growth over the areas where the sludge was entrenched.)

Figure 29. Fescue in December 1973 growing over entrenched digested sludge on plot Ia in upper right hand corner above line and over control V on left side of photo. Arrows point to fescue growing over areas in control where sludge was entrenched by mistake.

As a third fact, the uptake of heavy metals from the soil or the sludge is greater under acidic than under neutral or basic conditions. The raw sludge treatments were limed and initially had higher pH levels (Table 5). With time, however, the pH of both the raw and the digested entrenched sludges became similar (Tables 31 to 34). A fourth fact is that the relatively high levels of phosphate in sludge reduce the availability of metals to plants.

As a fifth factor, the uptake by a given plant species is dependent upon the total metal level present. The raw sludge had approximately one-fourth to one-half as much total zinc and copper as the digested sludge (Tables 31 to 34). Finally, the roots of plants penetrate raw sludge less readily than digested sludge and have less root absorptive surface exposed to metals.

Looking at the uptake-translocation of heavy metals into tall fescue tops on a given date (Table 35), the zinc uptake was apparently the only metal uptake significantly affected by sludge properties and trenching method. The relative rank as to amount of zinc uptake by the fescue was: digested 60 x 60 cm (I)> digested 60 x 120 cm (II) = raw-limed liquid 60 x 120 cm (IV) = trenched control (V)> raw-limed 60 x 60 cm (III)> surface control. At this time roots had not penetrated to a great degree through the deeper soil cover over entrenched sludge in plots II and IV.

Zinc uptake-translocation from the trenched control (V) was greater than from the surface control, probably because crops were growing in the acid subsoils. These acid subsoils were low in phosphate and organic matter levels -- all conditions that promote uptake-translocation of zinc to fescue tops.

Uptake-translocations of zinc from the raw-limed sludge trench plot (III) was even less than uptake from the trenched soil control (V), apparently because the excess lime in the sludge raised the subsoil pH and decreased zinc uptake, because the high sludge phosphate concentration decreased zinc uptake, and because the total metal concentrations were one-fourth to one-half of that in the digested sludge. In this case sludge reduced uptake of metals to levels lower than those which naturally occurred from the acid subsoil of the trenched soil control. Uptake-translocation of zinc was least in the unsludged surface soil control where no sludge metals were added and where higher phosphate and organic matter and lower acidity reduced uptake of native metals.

Uptake of zinc, copper, and nickel was less for all treatments in November 1973 than in September 1973, and indicated that zinc in the sludge had become slightly less available and copper and nickel in the sludge considerably less available with time after the sludge was entrenched. The decrease in availability was in contrast with increased DTPA-TEA extractable (available or potentially toxic) sludge zinc, nickel, and particularly copper as sludge dewatered (Tables 31 to 34). The reason for the decrease in uptake-translocation of copper and nickel in 1973 is not known. Perhaps it was due to destruction of plant-absorbable chelates of these metals by the action of dewatering and the aerobic conditions. On the other hand uptake-translocation of both copper and nickel were also less in unsludged controls in 1973 than in 1972.

Soybeans-1972 -- There was essentially no yield of beans because of wild animal injury to the crops.

Fruit and Shade Trees - 1972-73 -- Fruit trees were planted in 1972 and 1973, according to the plan indicated in Table 36 and Figures 15 and 16, in completely fertilized controls and without fertilizer in the trenched areas. Fruit trees, started in 1972, were planted too late in the season. The fruit trees also were held dormant too long and as a result some varieties died enmasse. As an exception, however, the peach trees faired very well. An exaggerated example of the effects of a tree being planted in a trenched area compared with a control is shown in Figure 30. The trees were planted in June 1972 and the photographs taken in October 1972. While the control tree received complete fertilizer, 225 mm (9 inches) of rain which fell during one week shortly after planting leached out most of the nutrients. The tree planted between two 120-cm deep trenches, however, received the same rain. In the latter area, however, the rain did not wash away the sludge-contained nutrients. The improved growth of the peach tree in the sludged area may also have been related to better water capture because it was planted in an area where the ridges were not flattened.

Peach tree growth in 1973 was more vigorous than in 1972 in both the sludge entrenched areas and in control areas. Control areas, however, still did not support tree growth as well as sludge entrenched areas. Most fruit trees planted in the spring of 1973 have survived. Peach trees are the fastest growing species. Differences between the growth of the slower growing tree species in the sludged and fertilized control areas were less readily apparent.

Analyses of peach tree leaves in 1972 to 73 show that some metals were being absorbed into the leaves (Table 37). Whether these metals would move in any quantity into the fruit and whether the movement would be a nutritional benefit or hazard remains to be seen in several years when the trees begin to produce fruit.

Shade trees planted in 1973 were small and were planted during the middle of the summer. We were unable to adequately water and care for the trees, and most died whether in control or trenched areas. The shade trees were replanted in 1973 according to the plan in Table 38 and Figures 15 and 16. These trees were again small and arrived late from the supplier. No significant observations can yet be made on the rather small amount of growth that has thus far occurred. We gave these trees better care, however, and 85 percent have survived. We replanted the trees in the spring of 1974.

Table 35. UPTAKE OF HEAVY METALS BY KENTUCKY-31 TALL FESCUE

Treatment	Tillage*	Metal, mg/kg dry sludge						
		9/1/72**			11/14/73+			9/1/72
		Zn	Cu	Ni	Zn	Cu	Ni	Pb
I	L	92	12	6	70	5	2	9
	D	74	14	4	-	-	-	9
	DR	98	16	7	105	7	3	9
I	mean	91	14	6	87	6	2	9
II	L	57	11	6	48	6	2	8
	D	50	11	5	-	-	-	11
	R	68	22	6	-	-	-	12
II	mean	56	13	6	48	6	2	10
III	L	29	11	5	20	4	<1	10
	D	30	14	3	18	4	<1	9
	R	34	17	2	22	4	<1	9
III	mean	31	14	3	20	4	<1	9
IV	B	50	14	4	-	-	-	9
V	Control++	50	12	6	57	5	2	12
External	Control+*	21	10	5	14	3	2	9
Plants directly over excavated trench								
Ia					286	8	9	
IIIa					37	6	4	

* L = left in ridges; D = leveled and disked; DR = leveled, disked, and ripped; B = backfilled, leveled, and disked

Continued

Table 35 (continued). UPTAKE OF HEAVY METALS BY KENTUCKY-31 TALL FESCUE

** Values were means of one representative sample each from treatment Ia and Ib. Background subtraction for light scattering interference was not applied for any element.

+ Values in only about one-half of the cases were means of one representative sample each from treatment Ia and Ib; other values are for representative sample from treatment Ia and Ib. Background subtraction for light scattering interference was applied to Ni determinations only.

++ Control that was trenched supposedly without sludge, but possibly had some sludge contamination in the soil surface.

+* Control external to the sludge plots which had no possibility for contamination.

Table 36. FRUIT TREE STATUS ON DECEMBER 4, 1973

Tree Row*	Direction	Tree Number 1	2	3	4	5	6	7	8	9	10	Plot
(i)	E	Mop** A dd	Map D	Mop A	Map A	Mop A dd	Jp A much dd	6p A mdd large	Jp A mdd	Jp A some dd	Jp A large	IIa 120 cm dig
(ii)	NE	Sc A	Vc A	Vc A	Ba A	Sa A	62p A ------	62p A big	62p A -----			Ia 60 cm dig
(iii)	NE	Ya A	Ya A	Ya A small	Op A	Map D	Map A	Fp A	Sp A	Sp A		Ia 60 cm dig
(iv)	N	Ra A	Sc D	Sc D	Vc D	Ba A	Sa A	Sa A	62p A	62p A	62p A	Ib 60 cm dig
(v)	N	Ya A	Ra A	Ga A	Ram D	Op A	Map A	Map A	Fp A	Sp A	Sp A	Ib 60 cm dig
(vi)	E	Mop D	Mop A small	Jp A large	6p A	Jp A small						a control
(vi)	E	Mop D	Mop A small	Jp A slight dd	Jp A	6p A						a control

Continued

Table 36 (Continued). FRUIT TREE STATUS ON DECEMBER 4, 1973

Tree Row	Direction	Tree Number 1	2	3	4	5	6	7	8	9	10	Plot
(vii)	E	61p A	61p A	Sa A	Ba A	Vc A	Vc A	Sc A				b control
(viii)	E	Flp A	1p A	Map A	Map A	Op A	Ga A	Ra D				b control

* Row locations on entrenched plots are given in Figure 16 except for control.

** Key: A = alive
D = dead
dd = deer damage

Mop = Moonglow pear
Map = Magness pear
Op = Old Home pear
Jp = Jefferson peach
6p = 6409 peach
62p = 62290 peach
61p = 6419 peach
Sp = Satsuma plum
Fp = Fruar plum
Flp = F13-60-53 plum
1p = 19941 plum

Sc = Schmidt cherry
Vc = Vista cherry
Ba = Blemril apricot
Sa = Sungiant apricot
Ya = York apple
Ra = Red Delicious apple
Ram = Red Delicious apple/MM106
Ga = Golden Delicious apple

Figure 30. Jefferson peach trees, similarly sized seedlings transplanted into soil between entrenched digested sludge and fertilized control soil in June 1972, photographed October 1972.

Table 37. HEAVY METAL LEVELS IN PEACH TREE LEAVES

Date	Metals μg/g of dry leaves from Jefferson peach			
	Zn	Cu	Ni	Pb
Control				
72	23.0	6.0	2.3	11.2
73	23.3	5.3	<0.5	-
Digested plot IIa (60 x 120 cm)				
72	49.5	9.3	2.2	8.8
73	48.3	6.9	<0.3	

<u>Comparative Crop Response on Plots "a" and "b"</u> -- The bulk of the 1972 and early 1973 crop observations were made in the "a" plots. The "a" plots received better irrigation and cultivation than the "b" plots because of the wet conditions in the latter area. During 1972, plots Ib and IIIb were very wet and did not yield good crops. Plot Ib and in part IIIb dried considerably during the summer of 1973. These areas have now been seeded with crops that can be studied in 1974. Prior to drying, part of plot Ib was so wet and difficult to work that many vehicles became mired. Considerably greater mixing of soil and sludge occurred in that region.

Table 38. SHADE TREE STATUS ON DECEMBER 4, 1973

Tree row*	Direction	Tree number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(xi)	N	WO** A	RO A	RO A	WO D	WO G	NM A	NM A	NM A	AE X						
(xii)	N	SXG G	UP A	UP A	SXG	SXG G	UP G	AE X	AE X	TP A	TP	TP A	WO G			
(xiii)	N	WO G	WO D	NM G	NM D	NM D	RO A	RO A	RO A	SXG D	SXG A dd	SXG D	AE X	AE X	AE X	
(xiv)	N	RO A	RO G	NM D	NM D	NM A	NM D	WO D	WO A	WO A	WO A	TP D	TP A	TP D	TP D	AE X
(xv)	N	AS A	AS A	AS A	PO A	PO A	PO A	PO A	SM A	UP D	UP A	SM A	SM A	SM A	RO A	RO A
(xvi)	N	SG X	SG X	SG X	AS A	SG G	AS G	WG A	WG A	WG A	WG A	UP A	UP G	UP A	UP D	AS A
(xvii)	N	WW A	X	TP A	TP A	TP A	X	WO D	WO A	TP A	SXG A	RO A				
(xviii)	N	SXG D	SXG D	WO A	UP A	WO D	UP A	WO G	NM A	NM A	NM A	RO A	RO A	RO A	RO A	
(xix)	N	SG G	SG A	SG A	WB A	WG A	WG A	NM A	NM A	AS X	AS X	AS X	NM D			

Continued

Table 38 (continued). SHADE TREE STATUS ON DECEMBER 4, 1973

Tree row*	Direction	Tree number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(xx)	N	TP A	UP A	UP A	UP G	UP A	UP A	PO A	PO A	PO A	SM A	SM A	SM A	NM A		
(xxi)	E	AS A	AS A	AS A	SM D	SM D dd	SM D dd									
(xxiii)	E	NM A	NM A	NM D	X	RO A	RO A									
(xxiv)	N	UP A	UP A	UP A	SG D	SG D	SG A									
(xxv) control	N	WG A	WG A	WG A	AE X	AE X	AE X	TP A	TP A	TP A	WO A	WO A	WO A	AS A	AS A	AS A
(xxvi)	N	NM A	NM A	NM A	SM A	SM A	SM A	RO A	RO A	RO A	PO A	PO A	PO A	SXG D	SXG D	SXG D

* Row locations on entrenched plots are given in Figure 16 except for controls.

** Key:
TP = tulip poplar
WW = weeping willow
WG = willow green
AE = American elm
UP = Ulmus parifolia
WO = willow oak
PO = pin oak
RO = red oak
NM = Norway maple
Sm = Silver maple
SXG = Sour gum
SG = Sweet gum
D = dead
A = alive
dd = deer damage
G = gone
X = not planted

SECTION V

SLUDGE pH TRIALS

INTRODUCTION

Liming sludges to pH 11.5 reportedly destroys pathogens. Liming can also influence availability of trace metals to plants and the release of nitrogen to plants and soil. In the trench studies of Section IV, we looked at the influence of high lime treatment in raw sludge only. In the following trials lime was applied to raw and digested sludge, and the sludges were incorporated into soils in surface and trench plots. In practice the amount of lime applied elevated the sludge pH to values ranging from just above the untreated sludge value (6.4 to 7.4) to in excess of 11.5. These trials were performed to observe the effects of liming to several different pH values on the survival of coliforms and salmonellae, on the fate of sludge nitrogen, on the sludge and soil pH, and on the growth of plants.

PROCEDURES

Digested and raw sludges were limed and treated at the Blue Plains (Washington, D.C.) and the Little Hunting Creek (Virginia) wastewater treatment plants respectively as shown in Table 39. These sludges were then trucked to Beltsville for incorporation into the trench and surface plots shown in Figure 31. Sludges began arriving on July 18, 1972. They were sampled and then incorporated into the plots.

For the trench plots, sludges were incorporated into two parallel 3-meter (10 foot) long trenches, 60 cm wide x 60 cm deep x 60 cm apart and covered with the excavated soil to a depth of approximately 30 cm (1 foot) (Figure 31). This trenching rate is equal to 735 dry metric tons/hectare (320 dry tons/acre). For the surface plots, the sludges were mixed into the surface 15 cm (6 inches) of soil with a rototiller at rates of application that varied between 55 to 115 dry metric tons/hectare (25 to 50 dry tons/acre). The surface plots were approximately 4.5 meters (15 feet) square. The plots were located on Galestown-Evesboro sandy loam soil just south of the plots described in Section IV.

Samples of the newly arriving sludges were analyzed for pH, nitrogen, and most probable number (MPN) of coliform and salmonella bacteria. The unreplicated plots were sampled periodically over a 17-month period. Five core samples of each entrenched sludge treatment were made into treatment composite samples on each sampling date. These core samples were taken from the interior of the trenches. Similarly five core samples from each soil-sludge surface treatment were made into surface treatment composites on each sample date. The core samples from the surface treatments were taken to a depth of 15 cm. Rye and alfalfa, and subsequently fescue, after the rye, were planted as shown in Figure 31. Plant response was rated.

Table 39. INITIAL CHARACTERISTICS OF DIGESTED AND RAW SLUDGES

Source	Date	pH	% Total solids in filter cake	Added before dewatering % of dry sludge basis: Lime	FeCl$_3$	Polymer	% organic carbon*: of dry sludge entrenchment	of surface treated soils 12/25/74
Blue Plains **	7/18/72	5.8	23	0	2.20	0.075	18.3	2.98
(Washington,	7/19/72	8.5	27	3.6	2.90	0.086	19.8	3.04
D.C.)	7/21/72	10.5/11.0	34	4.6	0.28	0.086	20.6	4.39
Digested	7/20/72	12.3	29	13.6	6.95	0.086	18.0	3.24
Little	7/21/72	6.4	13	0	-	-	25.9	5.18
Hunting +	7/20/72	11.2	16	3.0	1.1	-	29.2	1.73
Creek, Va.	7/19/72	12.1	17	4.5	-	-	25.6	2.01
Soil control		5.3						1.00

* Calculated in Biological Waste Management Lab., ARS.

** Data supplied by Owen W. Taylor, Sludge Processing, Blue Plains, Washington, D.C.

\+ Data supplied by Buddy Morrison, Little Hunting Creek, Va.

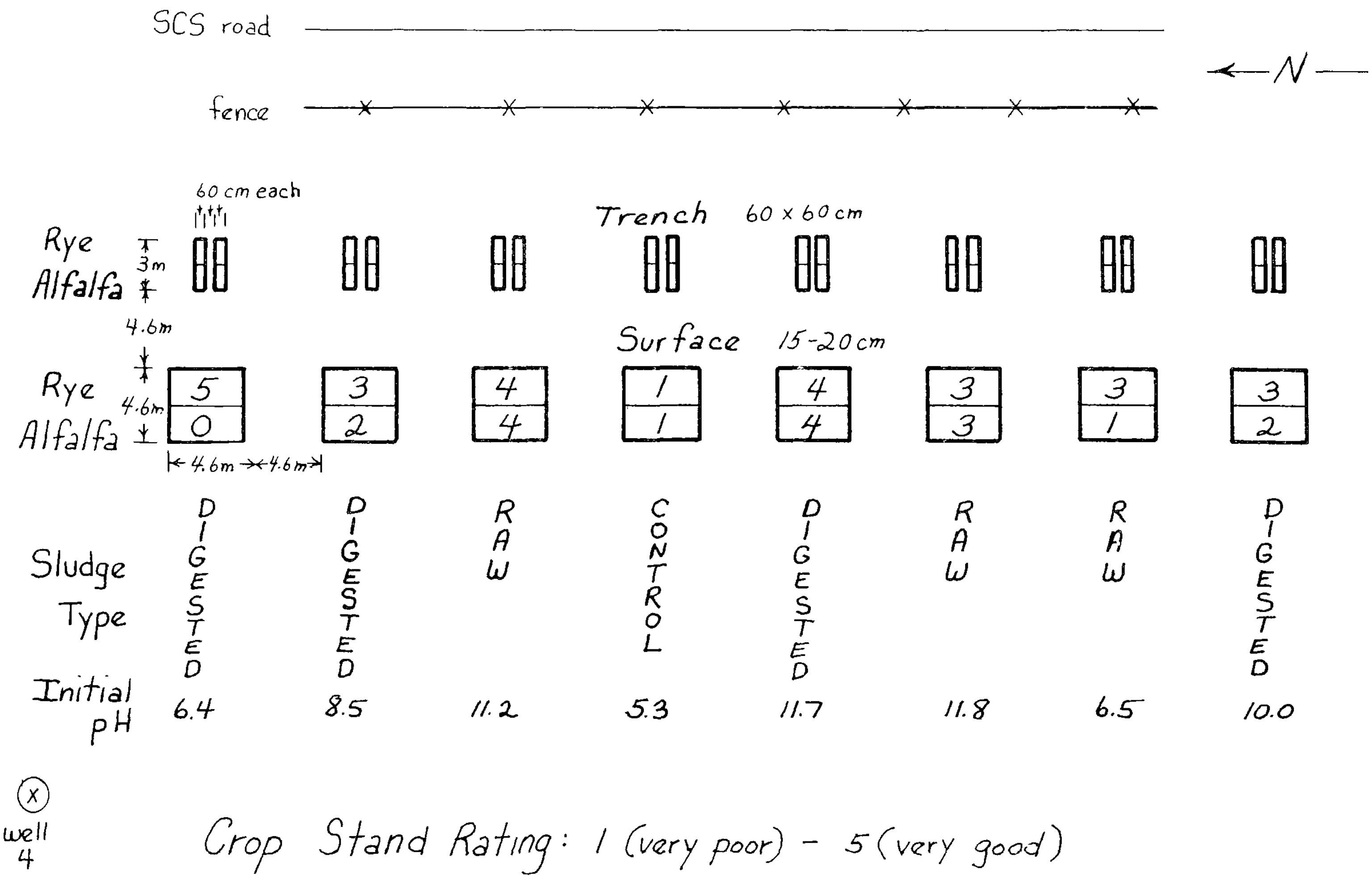


Figure 31. Trench and surface plot layout for sludge pH investigations with April 1973 crop ratings.

RESULTS AND DISCUSSION

pH

The initial sludge pH values in Table 39 were determined at the treatment plant and the initial and subsequent pH values in Table 40 were determined in our laboratory. The differences in initial values were probably a result of an actual change in pH from time of preparation to time of delivery. There was also, of course, the problem of variability encountered in sampling a large mass that may not have been homogeneous.

The initial pH ranges from 6.8 to 10.6 for the entrenched digested sludges and from 6.5 to 11.2 for the entrenched raw sludges (Table 40) were respectively narrowed to values of 7.0 to 7.6 and 6.4 to 7.6 within 3 months after entrenchment. By the end of 17 months, the pH of the unlimed digested and raw sludges had dropped to 5.1 and 6.1, respectively. Limed digested and raw sludges, as expected, were buffered more than the unlimed sludges, and pH values remained above 6.1 and 6.8, respectively. The pH of the surface plots were rapidly elevated to the levels shown in Table 40 by addition of the different sludges, and after 3 months reached more or less a new equilibrium.

Organic Matter

As one would expect, the organic content of the digested sludge was lower than that of the raw sludge (Table 39). The soil organic matter contents of the surface application plots were substantially increased by the addition of the sludge. The range in organic matter values reflected, within the rather large limits of sampling and analytical error, the range in rates of sludge addition to the plots.

Total and Fecal Coliform

As shown in Figure 32, the MPN's of total coliforms in the trench plots were initially much lower in the high pH sludge than in the low and intermediate pH sludge treatments. One to three months after entrenchment in the soil, the coliform numbers in the high lime treatments had increased while those in the other treatments with the exception of the pH 10.0 treatments in the digested and raw trenches had decreased. There was little, if any, real difference in coliform survival between the treatments with and those without lime. Apparently, the high lime treatment greatly decreased coliform numbers initially, but later actually stimulated growth, perhaps through solubilization of substrate for use by the bacteria or by production of a more favorable pH for their growth after conversion of $Ca(OH)_2$ to $CaCO_3$.

During the period from the third month to the 17th month after entrenchment, the MPN of total coliforms in the raw and digested sludges fluctuated around a mean of 10^5 MPN per gram. The variability in total coliform numbers was considerably greater in the digested than in the

Table 40. ENTRENCHED AND SOIL-MIXED SLUDGE pH WITH TIME

Sludge Type	pH Months after sludge entrenchment 0 7/18-22/72	0.25 7/26	0.5 8/1	3 10/10	4 11/20	6 1/31/73	8 3/30	9 4/26	10 5/30	17 12/13
	6.4	-	6.8	7.0	6.9	6.1	4.6	7.1	6.7	5.1
	8.5	-	7.2	7.5	7.0	-	6.4	7.4	7.3	6.4
Digested	10.0	-	7.9	7.3	7.3	-	6.1	7.5	7.2	6.8
	11.7	-	10.6	7.6	7.1	6.6	6.7	7.4	7.1	7.0
	6.5	-	6.5	6.4	6.7	-	6.7	7.2	7.5	6.1
Raw	11.2	-	9.6	7.6	7.2	-	7.8	7.4	7.3	7.3
	11.8	-	11.2	7.4	7.0	-	6.8	7.3	7.0	7.2
Control	5.3	-	5.4	5.1	4.6	5.5	4.4	6.0	5.0	5.2
				Months after surface mixing						
	6.4	6.2	6.3	5.2	5.1	6.4	5.2	6.1	5.6	5.4
	8.5	6.7	7.0	5.9	5.6	6.2	6.1	6.4	6.8	6.2
Digested	10.0	7.8	7.8	7.1	6.8	6.3	6.2	6.6	6.0	6.7
	11.7	8.1	7.8	7.4	7.4	7.3	6.6	7.2	7.2	7.6
	6.5	6.4	6.8	4.9	5.1	5.7	5.6	6.0	4.8	5.2
Raw	11.2	7.9	7.8	7.1	6.9	7.1	6.5	7.1	5.0	7.3
	11.8	8.0	7.4	7.4	7.5	7.4	6.8	7.2	7.2	7.5
Control	5.3	5.6	5.2	4.8	4.9	6.1	5.2	6.2	5.0	5.4

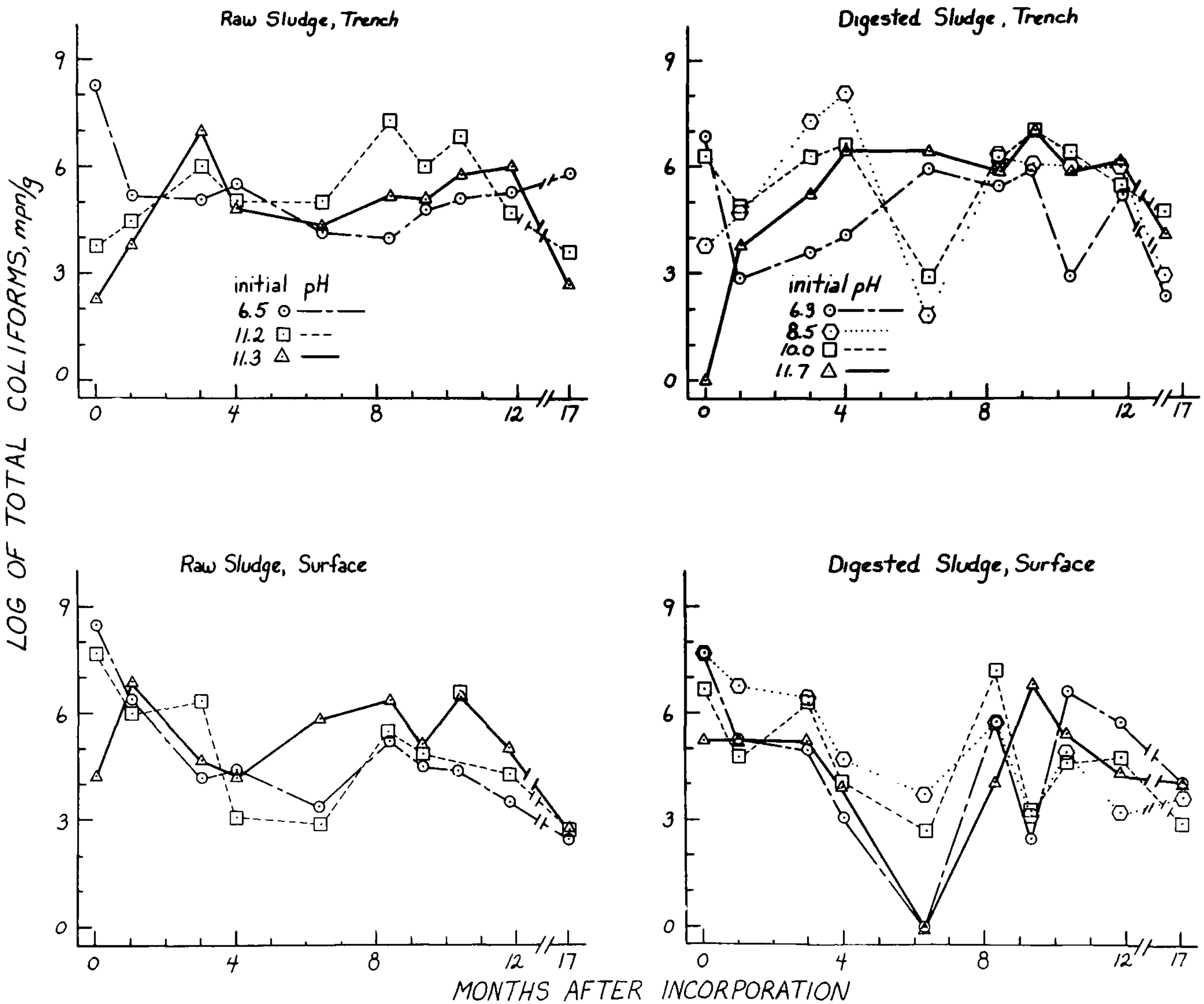


Figure 32. Survival of total coliform in entrenched and surface incorporated limed and unlimed raw and digested sludges.

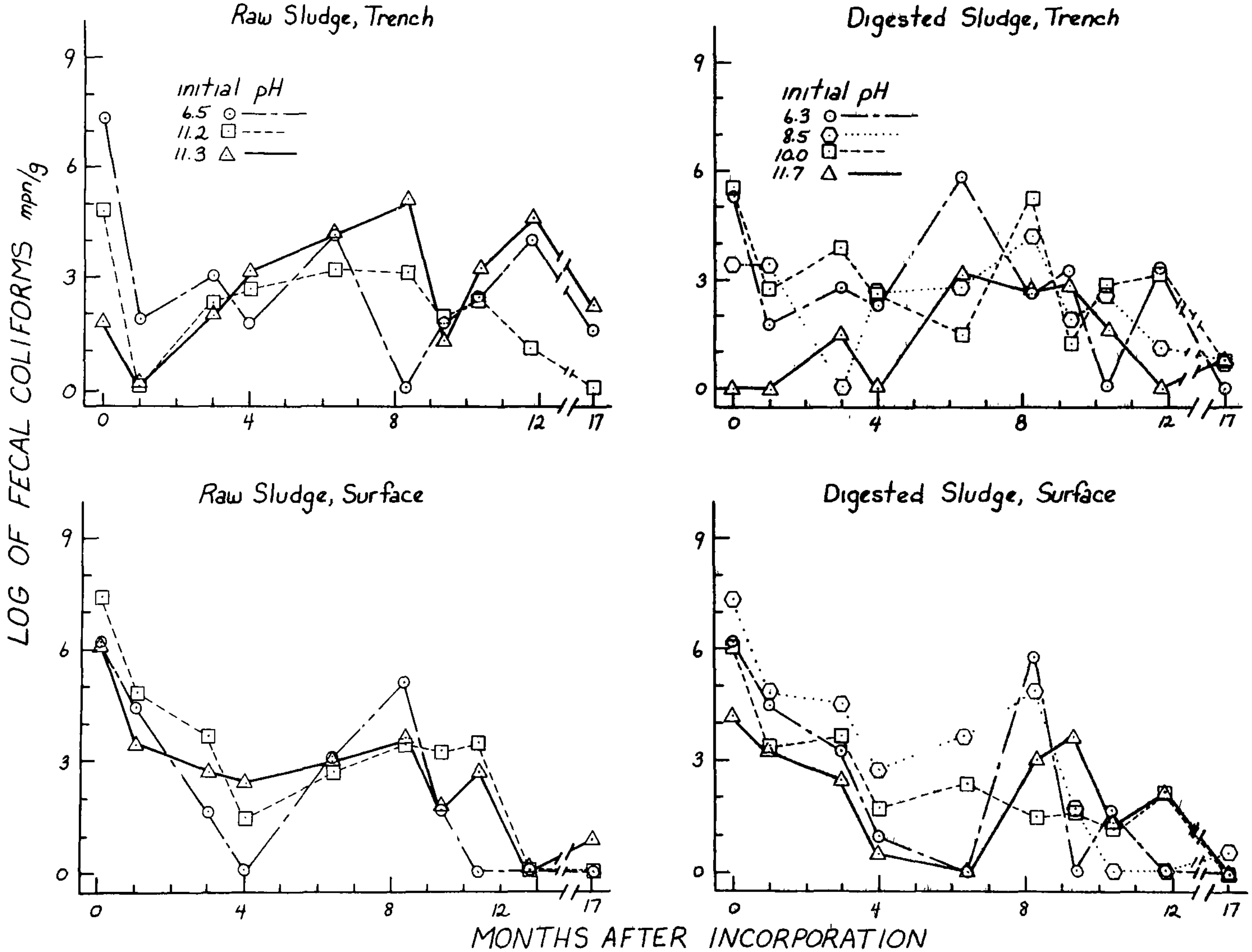


Figure 33. Survival of fecal coliform in entrenched and surface incorporated limed and unlimed raw and digested sludges.

raw sludge. Total coliform counts in the sludges did not really change much after the third month of entrenchment.

In the surface plots, as in the trench plots, the initial numbers of total coliforms were lower in the high lime treatments, but by the end of the sampling period, there was little difference in the treatments. Again there was a much greater variability in coliform numbers in digested than in raw sludge. The coliform numbers in the digested sludge treatments seemed to decrease in the winter months and increase again in warmer weather.

The MPN's of fecal coliforms in the entrenched raw and digested sludges are shown in Figure 33. As with total coliforms, the numbers of fecal coliforms were initially much lower in the high pH sludge than in the low and intermediate pH sludges. As with total coliform survival at 1 to 3 months after entrenchment, there was little, if any, real difference in fecal coliform survival in the sludge treatments with and without lime. The MPN of fecal coliforms in both raw and digested sludges averaged about 10^2 MPN per gram with counts only slightly higher, if at all, in the raw sludge treatments.

As shown in Figure 33, the fecal coliform data for the trench and surface plots were similar to those of the total coliform data with the initial difference in MPN counts for the lime treatments disappearing with time. The proportion of fecal coliforms surviving by the end of the study, however, was smaller than in the case of the total coliforms. This was essentially true for all treatments in both trench and surface plots.

The rapid decrease in distinguishable differences of lime effects on coliform numbers in sludge probably coincided with the conversion of excess $Ca(OH)_2$ to $CaCO_3$ and the resultant near equalization of pH among the treatments. As the pH decreased in the high lime treatments, the few coliform microorganisms present began to multiply and grow. Numbers therefore of both total and fecal coliform microorganisms are not a good index of pathogenic organisms that are incapable of growth outside of their human host.

Salmonellae

Salmonellae survived at least 8 months in the trenches and up to 17 months in the surface treated plots (Table 41 and 42). As with coliforms, the lime treatments (including the highest lime treatment), while reducing the levels of salmonellae to very low numbers initially, were not effective in their elimination. The salmonellae apparently regrew, as did the coliforms, when pH conditions became more favorable. Unlike the coliform bacteria, however, these organisms persisted only at low levels. They were usually below the detectable limits within 3 months after incorporation into the surface and trench plots. Persistence was somewhat greater in raw than in the digested sludges. There was no

Table 41. SURVIVAL OF SALMONELLA BACTERIA IN ENTRENCHED LIMED AND UNLIMED RAW AND DIGESTED SLUDGE

Sludge Type	Initial pH	Salmonellae, MPN/g dry weight Months after sludge entrenchment								
		0	1.5	3	4	6	8	10	12	17
		7/8-22/72	9/1	10/10	11/21	1/31/73	3/30	5/30	7/18	12/13
	6.4	34	8	<5	<4	6	<6	<10	<10	<7
	8.5	14	<8	<6	<4	17	<5	<10	<12	<6
Digested	10.0	21	42	<6	<5	<6	7	<15	<10	<7
	11.7	<61	17	<4	<5	<5	<7	<10	<1	<5
	6.5	227	<3	<4	<4	<5	410	<12	<13	<8
Raw	11.2	44	<7	<6	<5	22	<5	<11	<10	<7
	11.8	13	<10	<8	5	34	<6	<11	<14	<6
Control	5.3	-	<3	<3	<4	<3	<3	<7	<6	<3

Table 42. SURVIVAL OF SALMONELLA BACTERIA IN SOIL SURFACE INCORPORATED LIMED AND UNLIMED RAW AND DIGESTED SLUDGE

Sludge Type	Initial pH	Salmonellae, MPN/g dry weight Months after sludge entrenchment								
		0 7/18-22/72	1.5 9/1	3 10/10	4 11/21	6 1/31/73	8 3/30	10 5/30	12 7/18	17 12/13
	6.4	33	< 3	< 4	< 4	4	< 4	< 7	< 6	< 3
	8.5	4	9	< 4	< 4	< 4	< 4	< 7	< 6	< 3
Digested	10.0	99	12	110	< 4	< 4	< 4	< 6	< 6	< 3
	11.7	7	18	< 10	< 4	< 4	9	< 9	< 6	< 4
	6.5	23	< 3	< 3	< 4	4	4	< 7	< 6	3
Raw	11.2	7	11	< 4	< 4	4	< 4	50	< 6	7
	11.8	3	6	< 4	18	< 4	< 4	< 7	< 6	< 3
Control	5.3	2	3	< 3	< 4	< 4	< 4	< 6	< 6	< 3

noticeable effect of liming on long-term persistence. During the 17 months a few samples positive to salmonellae were found at random among the treatments in both the raw and digested sludges. Fewer positive samples were found in the entrenched sludges than in the surface applied sludges.

Nitrogen

While large quantities of ammonium-nitrogen (NH_4-N) were found shortly after sludge entrenchment (Table 43), little NH_4-N was present at zero time in the higher pH raw sludges and the highest pH digested sludge. Volatilization of the NH_4-N during liming, dewatering, and transportation to the site caused low initial ammonium concentration. Low oxygen levels found initially in entrenched sludges of Sections IV and VI indicated that these entrenched sludges were also initially anaerobic. After the initial increase in NH_4-N, the concentrations of NH_4-N decreased with time. The fate of the ammonium is not known. Possibly it was immobilized or denitrified as the sludge became more aerobic. If nitrified, it must have been rapidly denitrified because the quantities of nitrate are not large enough to account for ammonium which disappeared the first 10 months. In almost every instance there was less ammonium present in the high than in the low pH sludge.

From 1.5 to 8 months after entrenchment more ammonium was found in the raw than in the digested entrenched sludge, and this reflected the expected larger amounts of more readily mineralizable nitrogen in the raw sludges. Variability in later samplings make extended comparison difficult.

In the study all samples were analyzed for nitrite and none was detected. Nitrate began to appear between the 10th and 12th month in both the digested and raw entrenched sludges. By the 12th month more nitrate was present in the entrenched digested sludge plots than in the entrenched raw sludge despite higher ammonification rates in the earlier months for the raw sludge plots.

The considerable increases in the nitrate-nitrogen (NO_3-N) concentrations, particularly in the digested sludges 12 to 17 months after entrenchment, probably also occurred in the large entrenchment plots (Section IV). The observed nitrate increases in these small plot studies probably correspond with the significantly greater movement of nitrate under the large digested sludge plots (I) than under the large raw-limed plots (III) (Section IV).

The drastic increases in NO_3-N concentrations with time, particularly in the digested sludge, probably also corresponded with sludge dewatering. Sludge dewatering is accelerated by root penetration, which in turn was much faster in digested than raw sludge. This dewatering caused the sludge to become peat-like, aerobic, and porous (See Section IV).

Table 43. NITRATE AND AMMONIUM NITROGEN WITH TIME AFTER ENTRENCHMENT OF LIMED AND UNLIMED RAW AND DIGESTED SLUDGES IN SOIL

Sludge type	Initial pH	NO_3-N,* µg/g dry weight basis; Months after sludge entrenchment									
		0	1.5	3	4	6	8	9	10	12	17
		7/18-22/72	9/1	10/10	11/20	1/31/73	3/30	4/26	5/30	7/18	12/13
	6.4	-	25	33	32	11	8	4	16	1,280	982
	8.5	-	22	20	40	49	12	20	15	1,089	11,157
Digested	10.0	164	21	9	21	35	182	20	18	1,300	5,807
	11.7	37	18	36	21	25	32	7	8	25	597
	6.5	112	18	38	182	28	7	17	3	16	152
Raw	11.2	41	81	22	12	28	20	13	12	291	1,739
	11.8	38	11	10	3	6	9	8	6	290	645
Control	5.3	-	4	14	56	3	5	3	15	10	4
		NH_4-N, µg/g dry weight basis									
	6.4	992	2,424	465	844	613	179	795	868	514	263
	8.5	390	2,047	1,041	539	193	337	1,612	1,340	66	56
Digested	10.0	690	2,078	122	768	1,482	97	1,548	1,039	130	1
	11.7	8	2,824	259	34	187	54	437	460	17	8
	6.5	2,464	3,578	1,458	1,576	1,673	506	792	180	383	28
Raw	11.2	34	5,380	1,206	315	747	228	425	705	43	95
	11.8	6	448	586	31	167	32	51	49	226	18
Control	5.3	45	8	5	12	3	3	3	3	4	3

* NO_3-N data of questionable value for first 10 months of study and might better be regarded as "trace".

Concentrations of NH_4-N in surface-incorporated digested and raw sludges initially averaged about 350 ppm (Table 44). During the first 3 months, except immediately at the time of entrenchment, the high pH limed digested sludge contained lower concentrations of NH_4-N than the low pH limed digested sludges. The concentrations of NH_4 — H dropped to low equilibrium levels of 3 to 5 ppm about 3 months after sludge incorporation except in the digested low pH limed sludge.

The levels of nitrate in soil-sludge surface plots generally increased for 3 months after incorporation. As in the trench plots, no nitrite was detected. There was a slight but persistent reduction in NO_3-N in the soils treated with high pH limed sludge. As winter approached NO_3-N levels became very low. They increased in the summer and then decreased again in the winter. There was little difference in NO_3-N concentrations in soils treated with raw or digested high or low pH limed sludge.

Plant Response

The growth responses of alfalfa and rye in soil amended with raw and digested high and low pH limed sludges were rated in April 1973. These ratings are given in Figure 31. Rye generally showed a favorable response to all sludge types and lime levels. Alfalfa, which requires a neutral pH, grew much better in the soils treated with the highest pH limed sludges. Alfalfa and rye responded favorably to entrenched sludge, as shown in Figure 34.

Table 44. NITRATE AND AMMONIUM NITROGEN WITH TIME AFTER SURFACE INCORPORATION OF LIMED AND UNLIMED RAW AND DIGESTED SLUDGES IN SOIL

Sludge type	Initial pH	NO_3-N, µg/g dry weight basis Months after surface incorporation									
		0 7/18-22/72	1.5 9/1	3 10/10	4 11/20	6 1/31/73	8 3/30	9 4/26	10 5/30	12 7/18	17 12/13
Digested	6.4	37	50	168	17	3	11	3	4	29	14
	8.5	-	138	246	13	3	7	3	6	17	9
	10.0	24	28	53	9	7	3	2	4	29	4
	11.7	62	80	57	10	4	4	3	15	23	5
Raw	6.5	-	62	116	10	3	2	2	5	16	2
	11.2	44	155	95	7	3	3	3	4	1100	4
	11.8	3	144	77	7	2	5	3	4	23	2
Control	5.3	-	41	38	9	3	4	3	110	4	3
		NH_4-N, µg/g dry weight basis									
Digested	6.4	353	314	110	11	8	8	12	5	52	10
	8.5	300	43	5	3	3	3	3	3	4	1
	10.0	364	22	3	3	4	3	2	2	4	1
	11.7	483	15	3	3	6	2	3	3	5	2
Raw	6.5	635	300	19	3	3	2	2	3	4	1
	11.2	340	19	3	3	3	2	6	3	152	2
	11.8	176	17	3	3	4	2	3	3	4	1
Control	5.3	34	11	8	3	3	2	3	48	9	1

Figure 34. Response of rye and alfalfa to entrenched sludge in May 1973.

SECTION VI

GREENHOUSE STUDIES - TRENCH SIMULATION

INTRODUCTION

Greenhouse experiments were run before and concurrent with the field studies on sludge utilization. The first of these experiments was run to test the trenching technique for raw and digested sludge prior to the field trenching studies. Simulated trenches of sludge were placed into soil from the field site in large boxes in the greenhouse. Physical and chemical changes of the entrenched sludge and surrounding soil were studied during the growth of a corn crop. The factors studied included gases, soil-sludge moisture, nitrogen, heavy metals, and biological changes. A more detailed second greenhouse experiment was run in which sludge pH was varied in addition to sludge type.

Knowledge of the gaseous state of the soil and sludge (aerobic - anaerobic conditions) is helpful in describing nitrogen mineralization, nitrification and denitrification. This in turn is useful in predicting the potential of nitrogen movement through soils as a factor in groundwater contamination. The gaseous phase of the soil and sludge exerts a pronounced effect upon plant growth. Gases such as methane and ethylene may be toxic to plants at relatively low levels. Extended periods of low oxygen and high carbon dioxide restrict root growth, reduce yields, and injure plants.

PROCEDURE

Profile Boxes

Sludge profile boxes were constructed. These boxes were 120 cm high, 60 cm wide, and 15 cm deep. The back, sides and bottom were of sheet aluminum and the front was a removable panel of 1.25 cm thick plexiglass.

The boxes were placed upright on a greenhouse bench and filled with soil and sludge. A schematic diagram illustrating the technique is shown in Figure 35. The idea was to simulate a vertical section from midpoint of a 60 cm (24 inch) wide trench to the midpoint of a 60 cm (24 inch) interval between trenches. The box was high enough to provide 30 cm (12 inches) of soil above and below the sludge.

The boxes were planted with corn. The growth of corn plants and the behavior of corn roots in relation to the buried sludge were observed throughout the experiment. Gas and moisture analyses of the soil atmosphere were conducted throughout the experiment. At the conclusion of the study, the front faces of the boxes were removed and soil was sampled

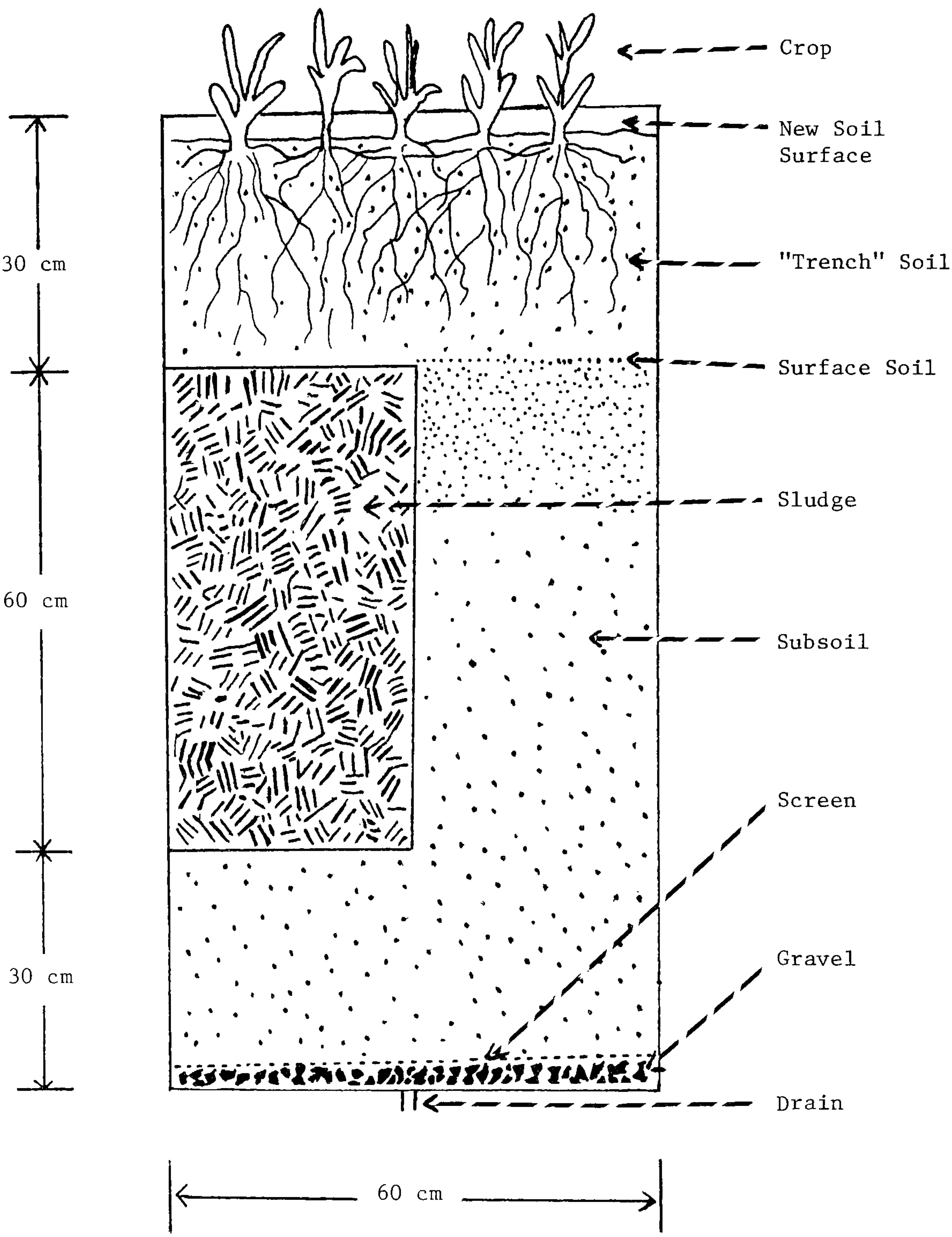


Figure 35. Diagram of trench simulation box.

in a grid pattern. The soil was analyzed for pH, total nitrogen, nitrate-nitrogen, ammonium-nitrogen, heavy metals, and salmonella, fecal coliform, and total coliform bacteria.

Soil Moisture

Moisture samples were taken periodically with an auger and determined gravimetrically.

Gas Analyses

Gas analyses were performed with an F&M 5750 research gas chromatograph equipped with a 0.25 cc sampling loop. Separation of carbon dioxide, methane, oxygen, and nitrogen was obtained by two 6.4 mm OD aluminum tubes packed with porapak Q and Linde molecular sieve 5^{o}A respectively. The two 6.4 mm OD tubes were separated by a 3.2 mm OD aluminum delaying coil to gain separation of individual gaseous peaks. Known standard gases were used for calibration to obtain quantitative results. Gas samples from the trench simulation boxes were obtained by use of needle equipped gas syringes through rubber septum ports spaced at intervals over the backs of the boxes. The rubber septums were fitted into nylon male connectors threaded into the backs of the aluminum boxes. Gas samples were protected in the syringes from atmospheric contamination during transport and storage by using serum caps or lock valves on the syringe ends.

Nitrogen Analyses

Total nitrogen was determined by the Kjeldahl method. Nitrate- and ammonium-nitrogen were extracted with a 4 to 1 solution of 1N K_2SO_4 and $0.03NAl_2(SO_4)_3$ to soil or sludge and determined by specific ion electrodes and microdiffusion as described in Section IV.

Heavy Metals

Heavy metals were extracted from soils with 0.005M DTPA-TEA, 0.01M $CaCl_2$, and 0.1M TEA at pH 7.3 and total metals in plants were solubilized by dry combustion and absorbed into HCl (Section IV). Analysis was by atomic absorption.

Bacteriological Analysis

Salmonella, fecal coliform, and total coliform bacteria were analyzed by procedures described in Section IV utilizing the most probable number (MPN) technique. The analyses were performed by the United States Department of Agriculture or the England Laboratories, Inc., Beltsville, Maryland.

Crop Growth

The growth of the corn plants and the behavior of corn roots in relation to the buried sludge were observed during the experiment. After the corn plants matured, the boxes were taken down and the soil, roots and sludge sampled on a grid pattern for chemical analyses.

Experiment 1

Digested sludge from the Blue Plains sewage plant was placed in one box and raw alum-sludge stabilized with lime was placed in the other. Corn was planted in each box and the plexiglass front covered with insulating board to keep the soil dark. Drainage water was collected from each box during a 5 month growth period and analyzed at intervals for nitrogen. Tensiometers were installed through the aluminum back of the boxes to measure water tension. The soil was a Galestown-Evesboro loamy sand from our proposed field trenching site. Experiment 1 was initiated in December 1971.

Six locations in the boxes were examined for gas composition. Two locations were in the soil 6 cm from the sludge-soil interface at 48 and 75 cm in depth. Two other locations were 8 and 20 cm deep in the sludge or 38 and 50 cm below the soil surface. The remaining locations were 2 cm below the sludge trench, 92 cm deep. One was 6 cm from the vertical edge of the soil-sludge interface and the other was centered directly below the sludge. Gas measurements were not made until 41 days after placement of the sludge in boxes. From then on they were made at weekly intervals up to the 138th day of the study.

Experiment 2

Experiment 2 was initiated in September 1972 approximately 4 months after the large field trenching study was initiated and 3 months after the field sludge pH studies were begun. Five trench simulation boxes were used. Each of the five simulated trench treatments were in Galestown-Evesboro loamy sand. They were: (a) control, (b) digested sludge medium pH (9.8) from Blue Plains, D.C., (c) digested sludge low pH (5.3) from Blue Plains, D.C., (d) raw sludge high pH (11.2) from Fairfax, Virginia (Little Hunting Creek), (e) raw sludge low pH (6.9) from Fairfax, Virginia (Little Hunting Creek).

RESULTS AND DISCUSSION - EXPERIMENT 1

Digested Sludge

Soil and Sludge Moisture -- The digested sludge subsided 7 to 10 cm during the 5 month period of the experiment. This subsidence was probably due mostly to packing of the sludge and squeezing out of air pockets and only slightly to direct water loss to the soil. The tensiometers showed that there was a very pronounced hydrostatic head (positive pressure) of water within the sludge. This was as high as 135 cm of water 2 days after sludge was placed in the trench and covered. Thereafter, the positive head varied during wetting and drying cycles as the corn crop was irrigated. Even after the corn roots had penetrated and extracted water from most of the sludge, the portion of sludge unexplored by roots maintained a slight positive hydrostatic pressure. This behavior of the sludge was in sharp contrast to the surrounding soil that was under moisture tension most of the time. This positive head indicated that water would likely not enter nor percolate through nonrooted entrenched digested sludge in the field for a considerable period of time.

Plant Growth -- The corn roots rapidly penetrated to the sludge layer and then were inhibited for about 2 or 3 weeks. After that time, they began to grow into the sludge, producing a very heavy mass of roots. These roots spread through the sludge, dewatering it and causing it to shrink and crack into small aggregates. By the time the corn matured, the roots had spread and dewatered all but about the bottom third of the trenched sludge (Figure 36). When the box was laid horizontally and the plexiglass removed at the end of the experiment, it was possible to lift out the sludge-root mass as a dry spongy, peat-like block (Figure 37).

After the sludge had been broken up and dewatered by the corn roots, it reabsorbed water readily but did not reswell. It now had become very permeable to water and air. The non-rooted sludge remained a barrier to water flow.

During the irrigation of the corn, sufficient water was added to produce drainage from the bottom of the box. The drain water from this digested sludge box was clear and almost odorless. This was in sharp contrast to the drain water from the alum-lime sludge which was reddish-brown in color and malodorous. This is described in more detail below.

Corn growth was excellent. The plants reached 180 cm in height and produced normal ears. There was no evident difference in growth between plants on top of the trench and those to the side. Chemical analyses of the plant material are being made.

Gas Analyses -- Gas composition data gathered at the representative sampling locations (in and just below the trenched sludge) are given in Figures 38 and 39. Figure 38 shows that the methane (CH_4) concentration in the digested sludge was very high from 41 to 75 days after sludge incroporation. During that same early period oxygen (O_2) concentrations were below 5% and carbon dioxide (CO_2) concentrations were above 17%. Obviously, therefore, anaerobic conditions prevailed during that period.

As roots penetrated the sludge in the region of the gas sampling port, CH_4 concentrations dropped precipitously, CO_2 concentrations also decreased, and oxygen concentrations increased. Roots were able to penetrate the sludge slowly in spite of high CH_4 and CO_2 and low O_2 Apparently penetration was initiated by the roots growing close to the sludge, dewatering a small area and causing it to become aerobic. Roots then grew into the newly aerobic area in the sludge, dewatering a new adjacent area, and so on.

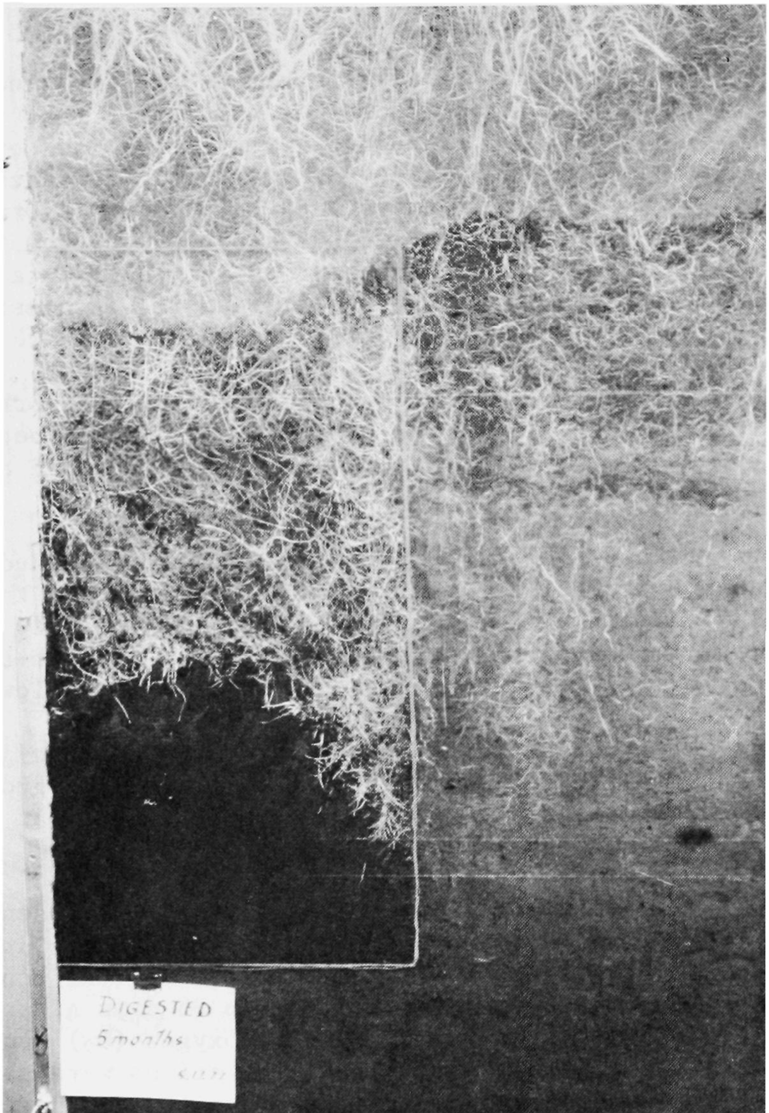


Figure 36. Penetration of corn roots into a simulated trench of digested sludge - 5 months after planting. The original cross-section of sludge addition is marked.

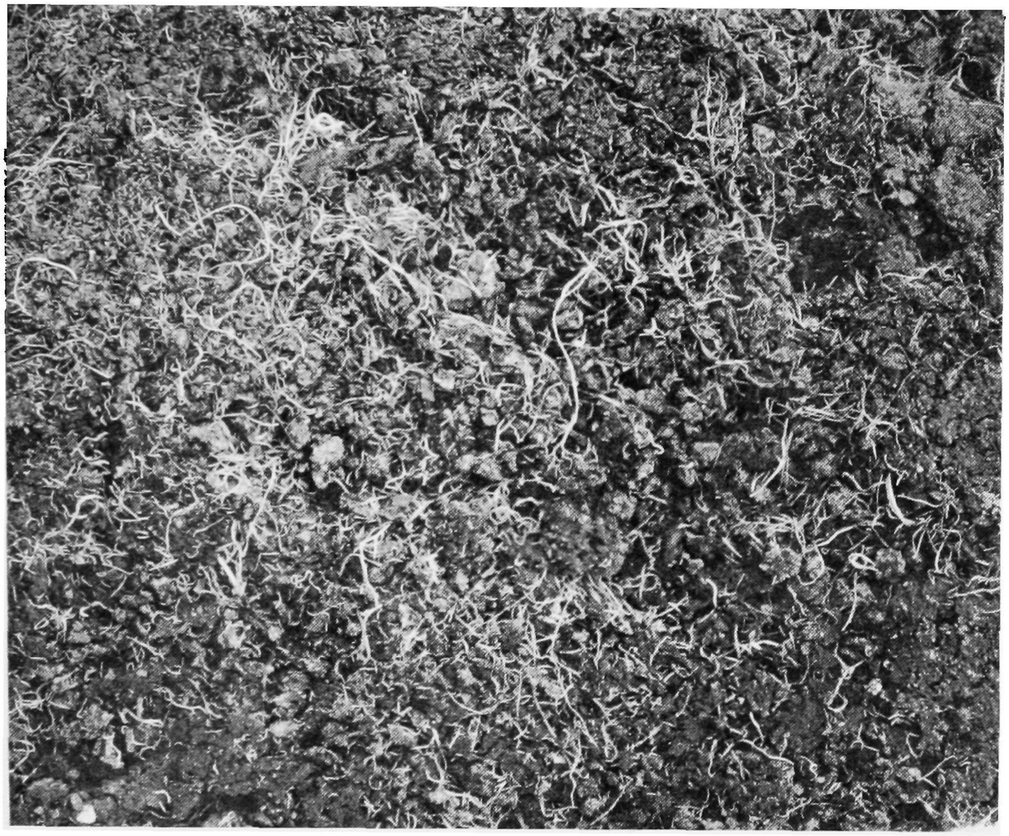


Figure 37. Appearance of digested sludge in simulated trench after penetration and dewatering by corn roots during a 5-month growth period.

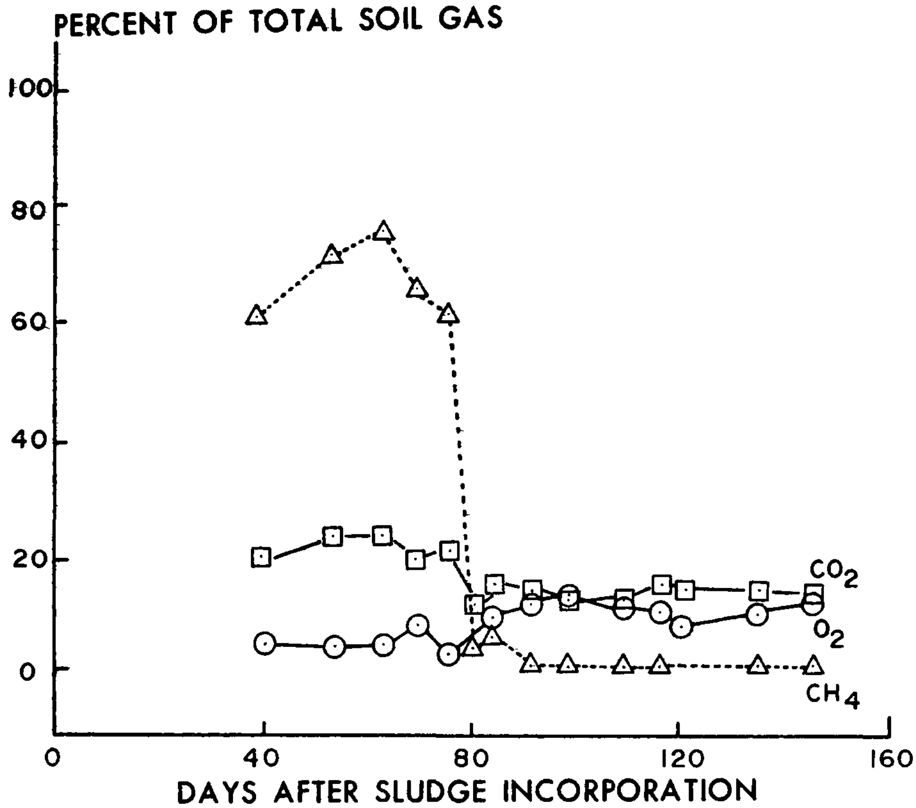


Figure 38. Methane, carbon dioxide, and oxygen levels within the simulated trench of digested sludge.

The data on soil gases below the sludge are shown in Figure 39. From 1% to 4% CH_4 was found in the soil during the period of 41 to 75 days after sludge incorporation. Oxygen levels were essentially below 6 percent throughout the experiment, while CO_2 levels were above 12 percent. This suggests that there were severe anaerobic conditions. After that period the soil atmosphere became slightly more aerobic but probably not enough to enhance root growth.

Nitrogen in Drainage Water

Data on the leachate are shown in Table 45. During the first 100 days, anaerobic conditions prevailed as indicated by the presence of CH_4 (Figure 39). During this period, nitrification was low as shown by low levels of nitrate-nitrogen. As aeration improved, nitrification increased and nitrate appeared in the leachate.

Although this suggests that nitrate pollution could become a problem with time, at least part of the nitrate content in the leachate may have been an artifact of the experimental technique. The sludge was observed to pull away from the plexiglass cover of the box and some water movement may have occurred at the soil-box cover interface, bypassing the more anaerobic zone directly below the sludge filled trench.

Zinc in Plants -- As plant roots explored the trench sludge area, the plants accumulated zinc. Table 46 shows concentrations of zinc in plants growing on profile box 1 where plant No. 1 is the plant furthest from the sludge and plant No. 11 is completely above the sludge area. An increased level of zinc occurred in the plants that were more nearly over the sludge than those which were further away.

Alum-Lime Sludge

The alum-lime (raw) sludge in the trench simulation trials behaved quite differently than did the digested sludge. The raw sludge was drier and more difficult to pack in the trench. It subsided more during the first week or so than did the digested sludge. Within a few days after assembling a very heavy growth of fungus mold appeared around the upper edge of entrenched sludge. Over the succeeding weeks it gradually spread downward as the sludge dewatered and shrank away from the observation window.

Plant Growth -- During the first 2 months the corn roots were unable to penetrate the alum-lime sludge. The roots grew down to the top of the sludge layer and stopped (Figure 40). A heavy massing of roots occurred at this location, all pointing down but not elongating. More and more roots accumulated here until they were tightly massed. In the meantime, the sludge had settled leaving a 1 to 3 cm air gap between roots and sludge. The roots did not pass this air gap, suggesting that a volatile inhibitor was involved. In spite of the root inhibition, almost normal top growth of corn occurred. After 3 months the roots began to penetrate a few cm into the surface of the sludge (Figure 41).

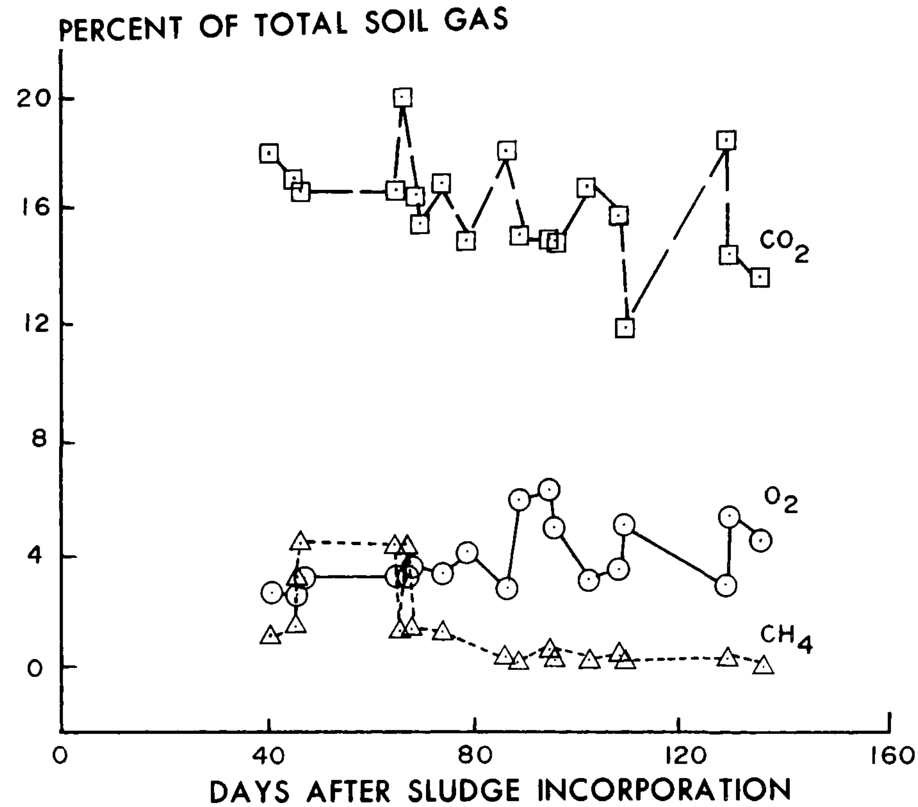


Figure 39. Methane, carbon dioxide, and oxygen levels in soil 2 cm below the simulated trench of digested sludge.

Table 45. NITROGEN COMPOUNDS IN DRAINAGE WATER FROM A TRENCH SIMULATION BOX CONTAINING DIGESTED SLUDGE*

Time after addition, days	Nitrogen analyses, mg/l			
	NH_4-N	NO_3-N	Org. N	Total N
93	26	0	10	36
101	68	2	4	74
117	97	25	6	128
124	93	30	116	239
137	88	45	3	137

* Leachate from the trench drained through 30 cm of loamy sand under the trench.

Table 46. ZINC CONTENT OF WHOLE CORN PLANTS GROWING IN A TRENCH SIMULATION BOX CONTAINING DIGESTED SLUDGE

Plant no.*	Zinc content µg/g dry weight
1	152
2	158
3	129
4	194
5	129
6	158
7	230
8	212
9	271
10	249
11	242

* Plant number 1 was furthest from sludge; plants number 7-11 were over sludge.

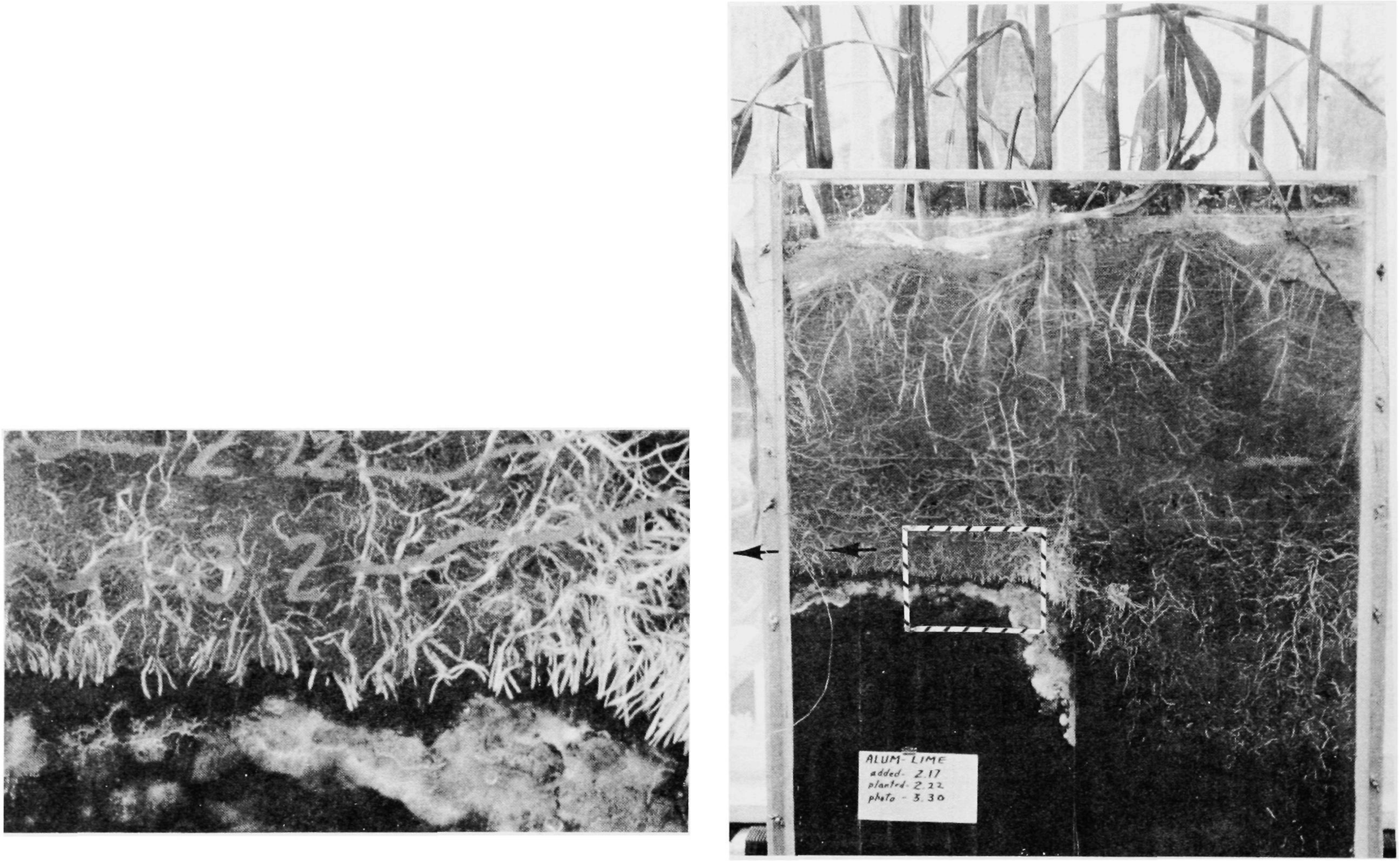


Figure 40. Corn root behavior in contact with "trench" of alum-lime sludge - 42 days after planting. Root growth has been arrested at the soil-sludge boundary. Note fungus mold growth on the sludge surface.

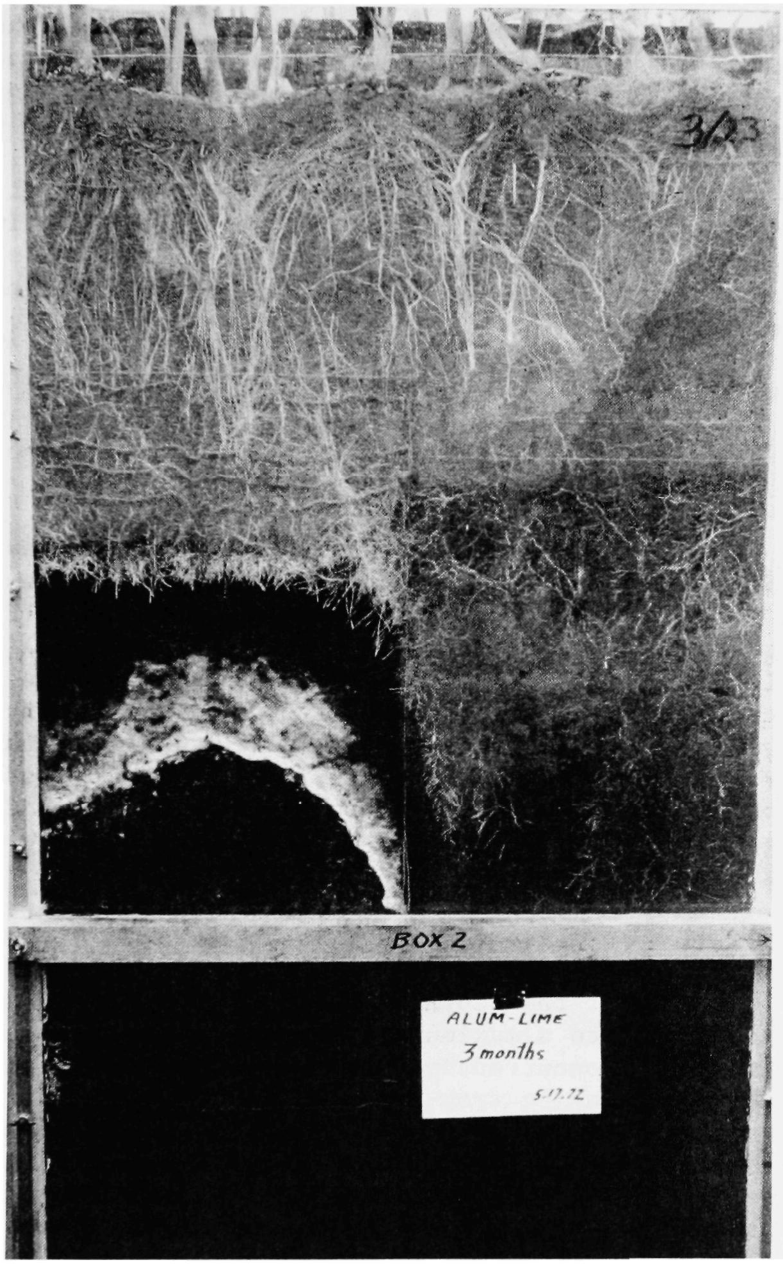


Figure 41. Corn root behavior in contact with "trench" of alum-lime sludge - 3 months after planting. Corn roots are just beginning to penetrate sludge, well back of the advancing front of heavy mold growth. This crop of corn matured without any further penetration of the roots.

By this time the plants were nearing maturity and root penetration ceased. The previously described fungus mold continued to grow as a zone of mycelium progressing downward slowly between the sludge and the observation glass. Behind the advancing edge of the mold the sludge was shrunken and dewatered. It appeared as though decomposition was aiding the dewatering process.

The raw alum-sludge seemed to allow water to pass through it and leach it, in contrast to the digested sludge which appeared relatively impervious in the wet state. The movement of water through the sludge occurred because of the shrinking and cracking of the sludges. The drainage water was reddish-brown, turbid, and foul smelling.

Corn growth was not as good on the alum-lime sludge as on the digested sludge. The plants were somewhat chlorotic and showed marginal burning of the lower leaves. The analysis of the plant tissue may offer some explanation of these symptoms.

Gas Analyses -- Gas composition data was gathered in the raw sludge trench simulation box at approximately the same two representative locations as in the digested sludge trench simulation box (Figures 42 and 43). Methane was present in the raw sludge (Figure 42) through all but the initial two weeks of the study. Carbon dioxide concentrations were also high (above 16%) throughout the study period. Oxygen concentrations were low, averaging about 4%, all emphasizing that anaerobic conditions prevailed throughout the experiment. In contrast with the high levels of CH_4 occurring early in the digested sludge, CH_4 levels in the raw sludge were low initially and high concentrations were not found until after about 70 days.

The effect of sludge on gaseous production in the soil atmosphere is shown in Figure 43. Methane was detected after 11 days and had increased to over 11% at the 126th sampling date. Carbon dioxide concentrations progressed to a maximum of 23% and at the 126 day sampling date were below 11%. Concurrently, the O_2 concentrations were low throughout the study ranging from 2% to 6%. This anaerobic condition can restrict root growth and affect plant development. These reduced conditions also restrict nitrogen mineralization and encourage denitrification. Consequently, one would expect little nitrate leaching until the soil atmosphere became aerobic.

Nitrogen in Drainage Water -- The nitrogen content of the drainage water was very high, especially in ammonium (Table 47). Evidently the very small exchange capacity of the loamy soil was quickly saturated, allowing ammonium to move through the profile. The highly anaerobic and richly organic conditions present were apparently unfavorable for the conversion of ammonium to nitrate, and/or considerable denitrification was occurring. These high concentrations of ammonium both within the sludge and in the soil are very toxic to root growth. The high concentrations of ammonium and other materials fouling the drainage water suggested that the capturing, impounding, and recycling of infiltrating rain water are particularly important in areas entrenched with raw sludge

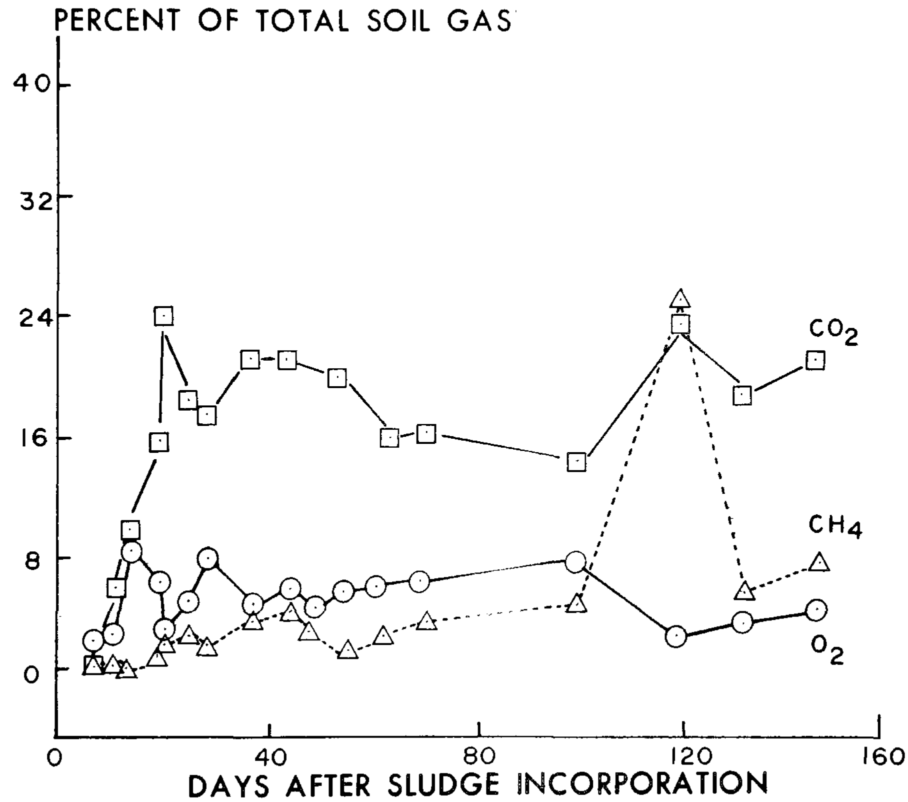


Figure 42. Methane, carbon dioxide, and oxygen levels within the simulated trench of raw alum-limed sludge.

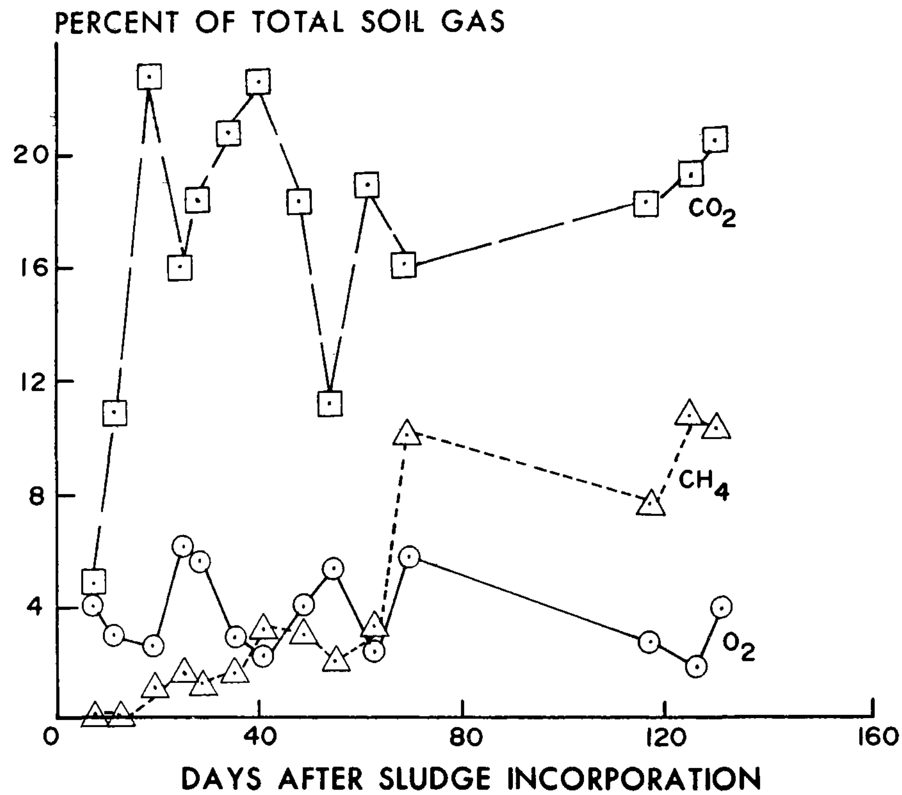


Figure 43. Methane, carbon dioxide, and oxygen levels in soil 6 cm below the simulated trench of raw alum-limed sludge.

Table 47. NITROGEN COMPOUNDS IN DRAINAGE WATER FROM A TRENCH SIMULATION BOX CONTAINING ALUM-LIME SLUDGE*

Time after sludge addition, days	Nitrogen analyses, mg/l			
	NH_4-N	NO_3-N	Org. N	Total N
19	24	1	14	38
21	81	6	24	90
28	825	33	8	866
34	1404	8	132	1544
41	1461	6	87	1554

* Leachate from the trench drained through 30 cm of loamy sand under the trench.

CONCLUSIONS - EXPERIMENT 1

Results obtained from the digested sludge trench simulation box in Experiment 1 showed (1) that considerable penetration of the sludge occurs by corn roots of healthy corn plants growing over the entrenched sludge, (2) that little percolation of water through the sludge occurs until after root penetration, and (3) that, while low oxygen concentrations and movement of organic materials along with nitrate-nitrogen would be favorable for denitrification, some movement of nitrate down through the soil profile is likely to occur.

Results from the raw alum sludge trench simulation box showed (1) that considerable delay of corn root penetration into the sludge and even into the soil immediately adjacent to the sludge and reduced vigor of corn occur. (The reason for poor root growth may have been due in part to high ammonium and low oxygen); (2) that water percolation occurs and is caused by considerable shrinkage and cracking not evident in the digested sludge; (3) that, as a result of appreciable movement of organics and low oxygen, considerable denitrification of nitrate-nitrogen is likely to occur under the trenches; and (4) that appreciable movement of ammonium-nitrogen is also likely to occur.

The results of the trench simulation box studies enabled us to predict in a rather short period of time what might happen in our field studies and thereby helped us plan the tests needed when we excavated trench cross sections in the field.

RESULTS AND DISCUSSION - EXPERIMENT 2

Introduction

A second series of trench simulation boxes was planned to investigate, under more controlled conditions than were possible in the field pH studies, the effect of sludge type and initial pH on soil-moisture, nitrogen transformation and movement, the gaseous atmosphere of the soil and sludge, soil and sludge pH, plant growth, pathogen persistence and movement, and heavy metal movement.

Soil Moisture

Soil moisture data are shown in Table 48. An attempt was made to keep the soil moisture in the five boxes at approximately the same level. During most of the experiments the moisture contents were similar for the five treatments. The Evesboro sandy loam is a droughty soil. The 0.1 bar value, which probably is close to field capacity, is only 6.3% and the 15 bar value (wilting point) is 1.2%. Until November 11 the soil was kept moist to facilitate corn growth. After that date corn development was rapid and transpiration was sufficiently great so that soil moisture was considerably lower. In the root zone (40 cm down from the top of the box) soil moisture remained between 0.1 bar and 15 bars except for February 15. Below a depth of 40 cm soil moisture was undoubtedly higher.

Soil and Sludge Nitrogen

The data for nitrogen in soil 161 days after sludge placement are presented in Figures 44, 45, and 46. Total nitrogen in the control box averaged 350 ppm (Figure 44). In both the digested sludge treatments, total nitrogen levels were higher in the soil adjacent to and below the sludge than elsewhere in the soil. In the raw treatment, total nitrogen was more than twice the control in the zone below and to the right of the sludge. This increase in total nitrogen indicated the movement of organic material from the sludge.

The ammonium data are given in Figure 45. In all treatments ammonium was considerably higher than the control. The greatest concentration of ammonium was found in the raw sludge treatments below and to the right of the sludge. It appears that in the digested treatments the organic nitrogen in the sludge ammonified and oxidized. Dewatering of the sludge by the corn roots produced favorable aerobic conditions for nitrification. In contrast in the raw sludge, which did not dewater, conditions were anaerobic and favored accumulation of ammonium and denitrification whenever nitrate was produced.

Table 48. SOIL MOISTURE PERCENT IN TRENCH SIMULATION BOXES AT 10 AND 40 cm

10 cm

Date	Control	Box: Digested High pH	Box: Digested Low pH	Box: Raw High pH	Box: Raw Low pH
9/27/72	10	10	10	10	11
10/5	9	8	9	9	6
10/13	6	5	14	16	5
10/25	9	10	7	9	8
10/31	10	10	12	11	12
11/10	17	13	14	14	14
11/21	1	2	<1	<1	3
11/28	10	11	11	9	9
12/8	1	2	2	1	1
12/23	1	6	4	2	2
1/5/73	6	3	4	6	6
1/11	2	6	1	1	1
1/19	1	4	7	1	1
1/26	1	2	1	1	1
2/2	1	1	1	1	1
2/15	1	1	1	1	1
2/23	4	2	2	1	2

40 cm

Date	Control	Box: Digested High pH	Box: Digested Low pH	Box: Raw High pH	Box: Raw Low pH
10/25/72	10	9	11	9	9
10/31	15	13	15	12	13
11/10	15	16	17	15	10
11/21	5	2	2	5	2
11/28	14	15	16	9	9
12/8	5	6	6	5	3
12/23	2	6	5	5	4
1/5/73	6	7	8	7	8
1/11	4	5	4	4	4
1/19	7	5	5	4	4
1/26	3	3	4	6	7
2/2	2	3	2	2	4
2/15	1	1	2	1	1
2/23	9	2	4	3	3

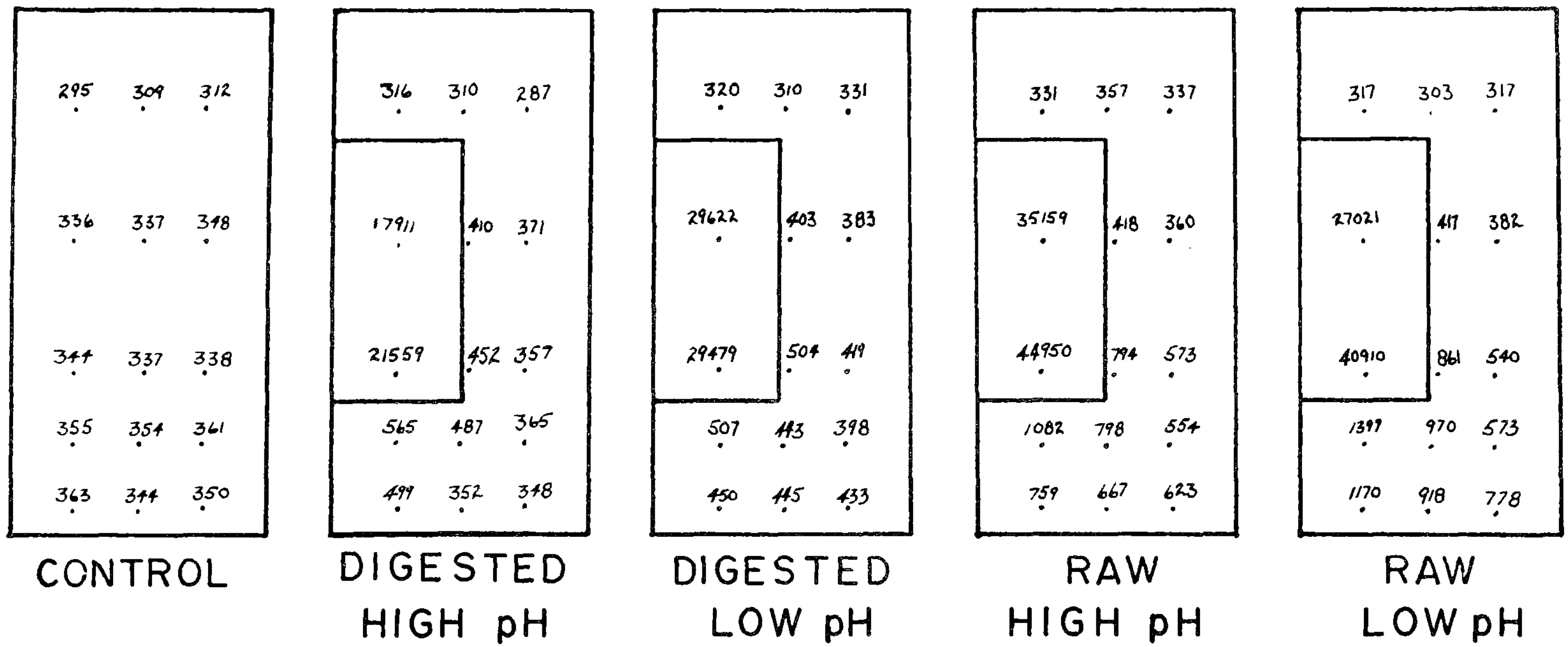


Figure 44. Total nitrogen (ppm) in trench simulation boxes after 161 days.

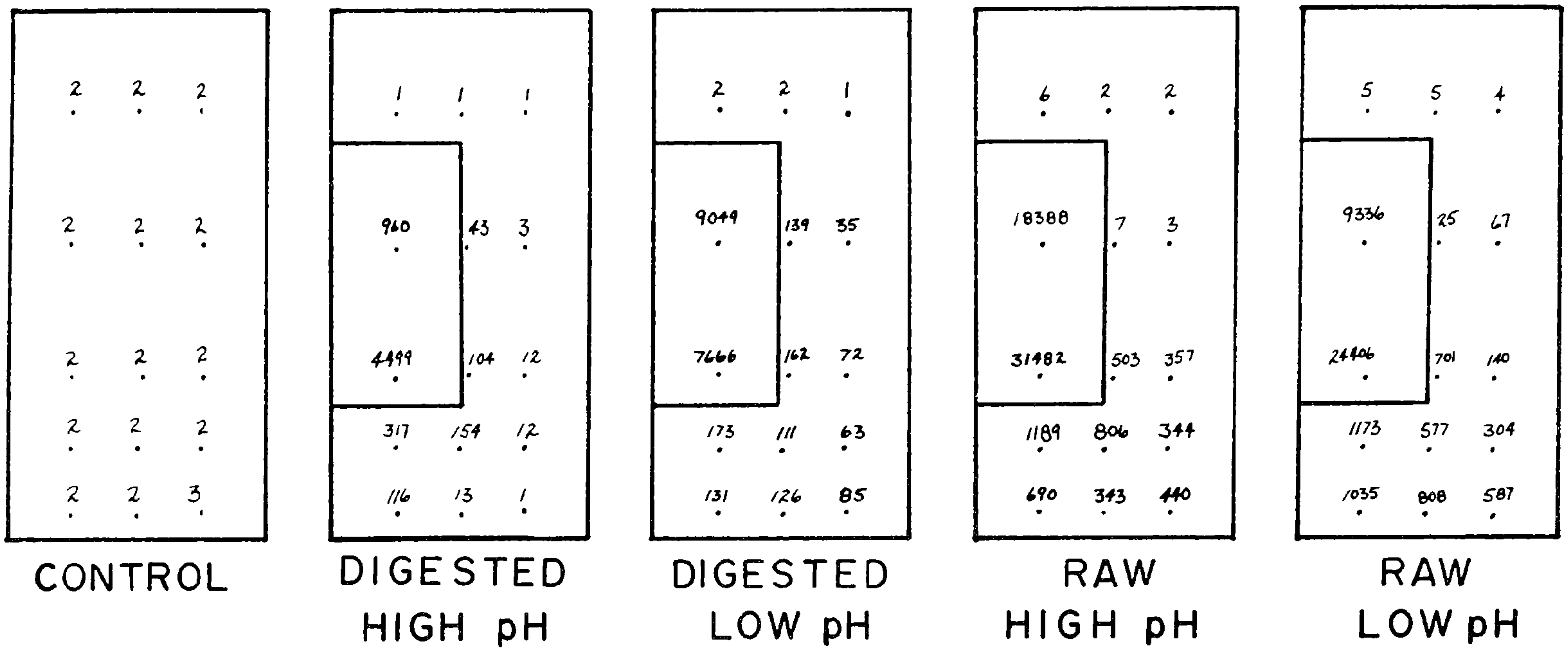


Figure 45. Ammonium-nitrogen (ppm) in trench simulation boxes after 161 days.

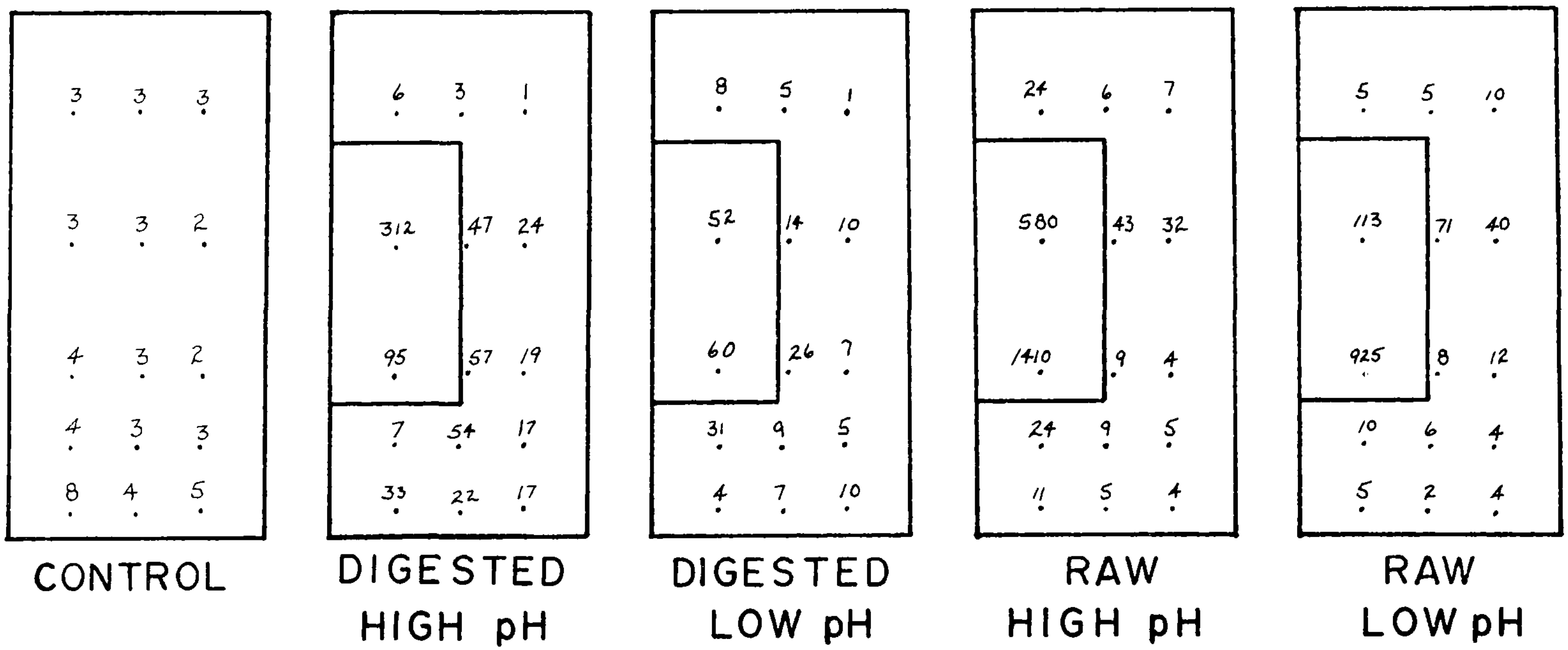


Figure 46. Nitrate-nitrogen (ppm) in trench simulation boxes after 161 days.

Nitrate-nitrogen (Figure 46) was higher in the digested treatments both in a horizontal and vertical direction from the sludge. The digested high pH treatment had the greatest movement of nitrates. At 20 cm below the sludge, nitrate values ranged from 17 to 33 ppm. The aerobic conditions prevailing in the digested treatment encourage mineralization of organic nitrogen to nitrates. Unless the nitrates are removed by roots or denitrified, they will be leached to the groundwater. In contrast, the digested low pH sludge nitrate values for the same position were 4 to 10 ppm. Very little nitrate was found in the raw sludge treatments. This was probably the result of anaerobic conditions inhibiting nitrification or possibly encouraging denitrification.

The pH data are given in Figure 47. The pH of the soil above the sludge in all treatments including the control is higher because the soil was limed at the time of planting. All sludge pH's were 8.1 or less, even though one was over 11 initially. The $Ca(OH)_2$ had converted to $CaCO_3$. The pH of the limed sludges on the average was higher than the pH of the unlimed sludges. The soil pH to the side and below both digested sludge treatments was low because of the presence of acidic nitrate. In contrast, the soil pH to the side and below the raw sludge treatments was high as a result of ammonification.

Gas Analyses

To illustrate the changes in the soil atmosphere as a result of sludge addition, a single location in the profile box was selected. The gas analyses data in the accompanying figures are from a location in the soil 98 cm from the surface and 8 cm under the trenched sludge.

Control -- Normal percentages of soil gases were found throughout the experiment. Oxygen was 20%, CO_2 was 1 percent, and there was no CH_4.

Digested High pH -- The data for CH_4, O_2, and CO_2 are shown in Figure 48A. At the locations sampled little CH_4 was found throughout the experiment. Oxygen concentrations remained generally high and there were no extensive periods of low oxygen levels. Carbon dioxide concentrations were, conversely, low. Carbon dioxide increased with depth as oxygen decreased. In general, the soil environment for the treatment appeared to be favorable for root growth.

Digested Low pH -- No CH_4 was found after 35 days (Figure 48B). Oxygen concentrations were lower than in the previous treatment and remained below 15% throughout the experiment. The low O_2 and high CO_2 could partially restrict root growth in this area. Carbon dioxide increased with depth in the soil and at one location reached a maximum of 21% (data not given).

Raw High pH -- This treatment showed severe reducing conditions (Figure 48C). Methane concentration increased after 60 days to a maximum of 14% on the 132nd day. Oxygen concentrations dropped to less than 4% in 30 days and remained below this concentration throughout the experiment. There was a continual increase in CO_2 concentrations. These conditions

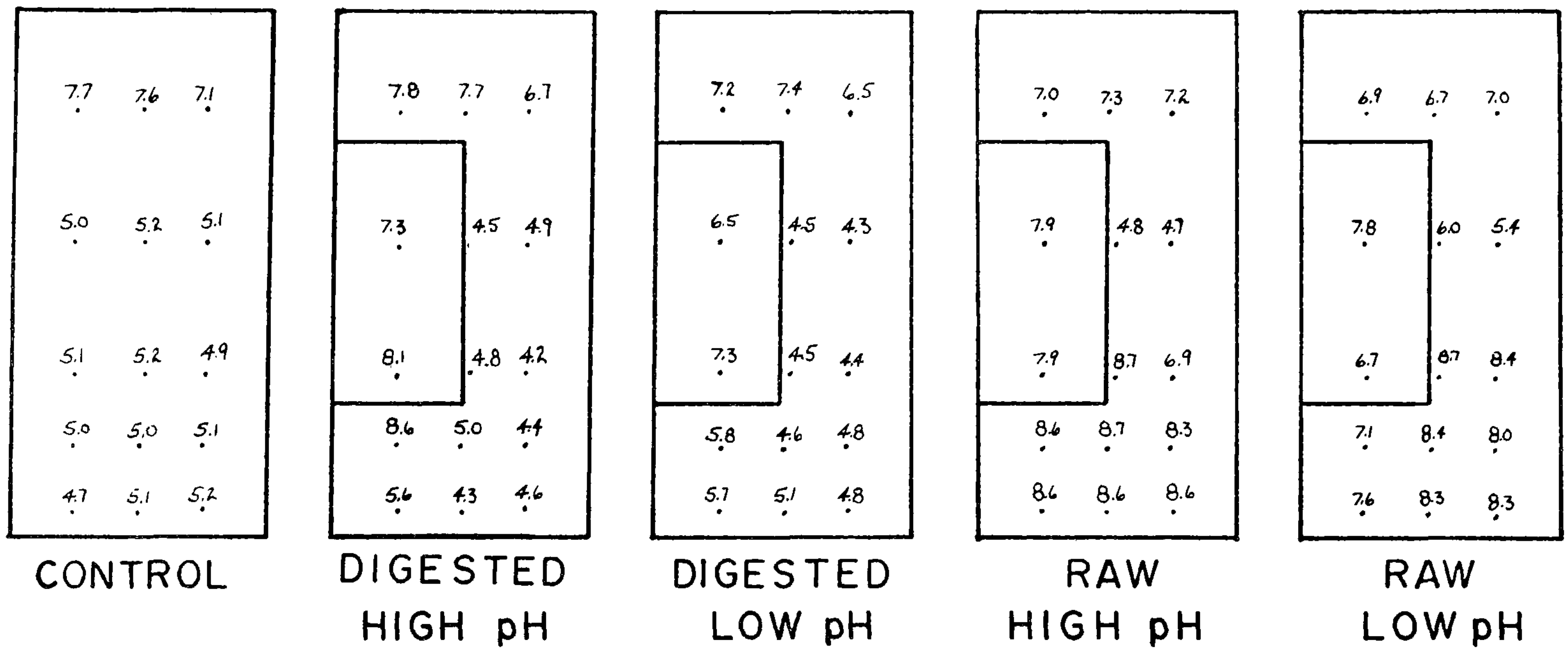
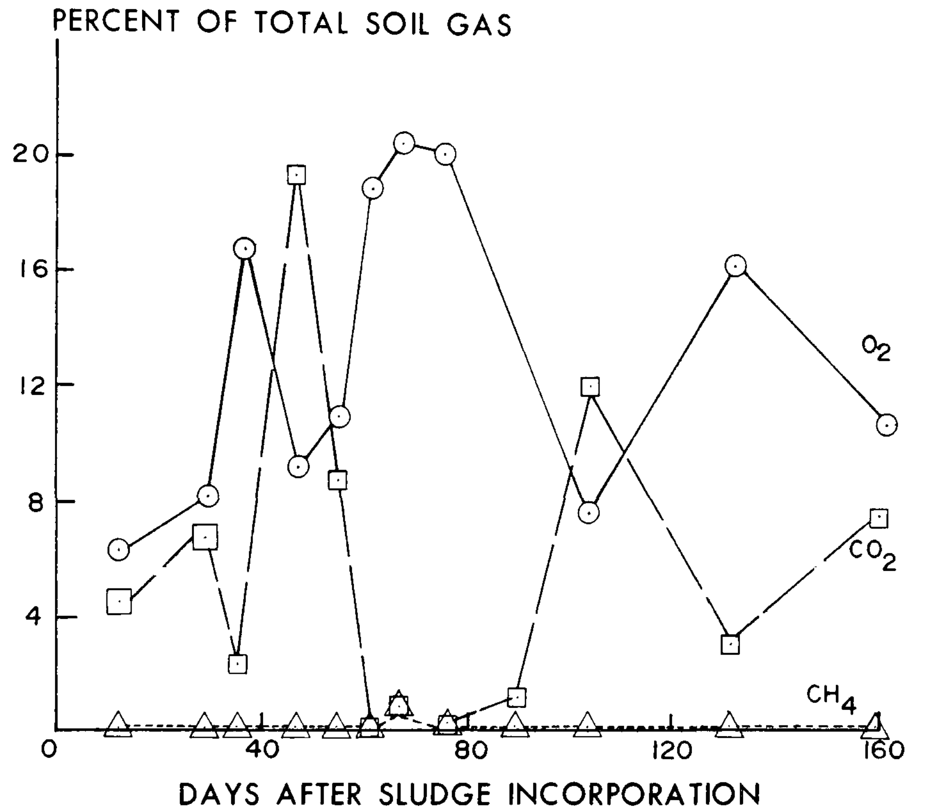
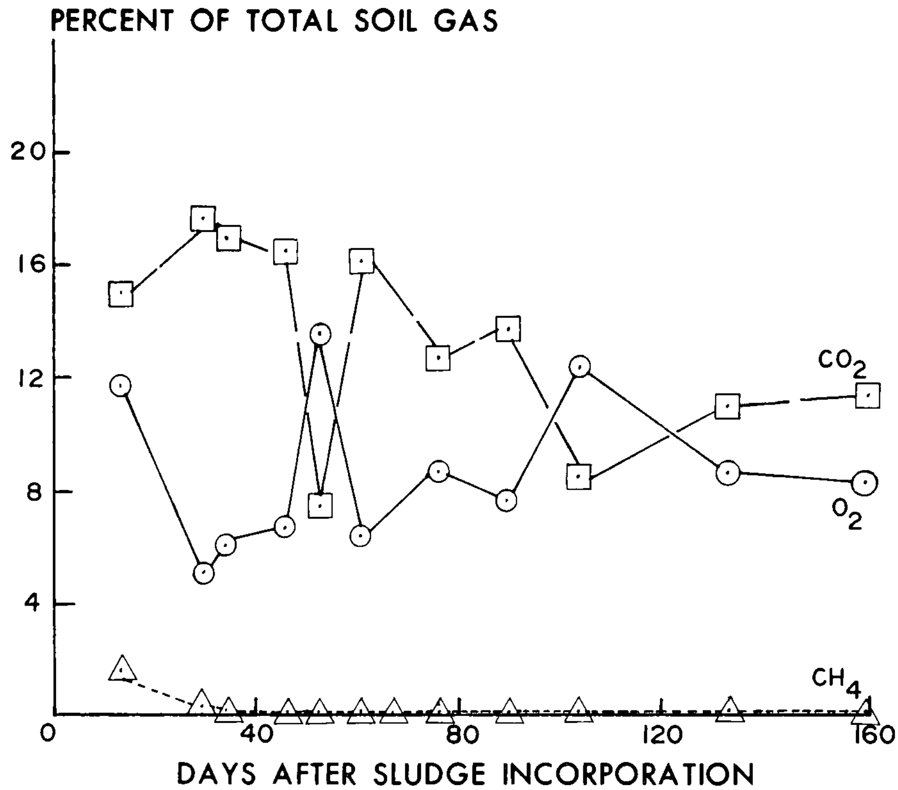


Figure 47. Soil and sludge pH in trench simulation boxes after 161 days.



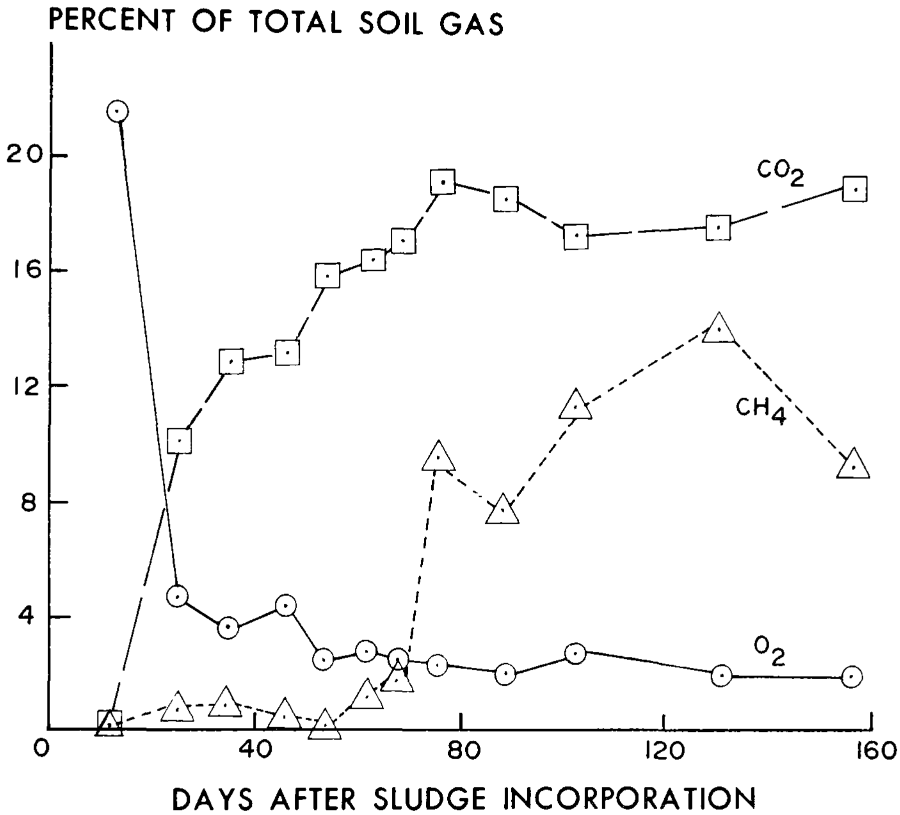
(A) Digested high pH sludge.

Figure 48. Methane, carbon dioxide, and oxygen levels in soil centered 8 cm below the simulated trench.



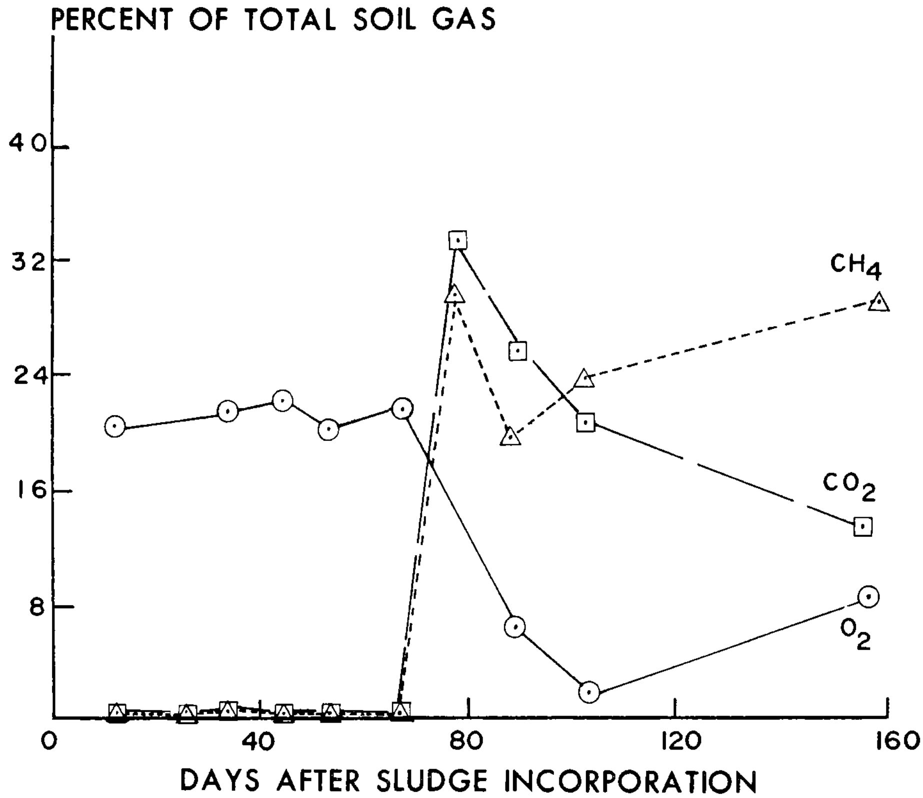
(B) Digested low pH sludge.

Figure 48 (continued). Methane, carbon dioxide, and oxygen levels in soil centered 8 cm below the simulated trench.



(C) Raw high pH sludge.

Figure 48 (continued). Methane, carbon dioxide, and oxygen levels in soil centered 8 cm below the simulated trench.



(D) Raw low pH sludge.

Figure 48 (continued). Methane, carbon dioxide, and oxygen levels in soil centered 8 cm below the simulated trench.

Table 49. HEIGHT AND STEM DIAMETER OF CORN PLANTS GROWING IN TRENCH SIMULATION BOXES AFTER 87 DAYS

Treatment	Plant height, cm	Stem diameter, mm
Control	85	87
Digested high pH	74	81
Digested low pH	73	96
Raw high pH	66	88
Raw low pH	69	91

restrict root growth and plant development. The anaerobic conditions, indicated by the data, also inhibited nitrification and enhanced denitrification if nitrate were formed. This was supported by the nitrate data as shown in Figure 46.

Raw Low pH -- This treatment behaved in a similar fashion to that depicted in the previous raw treatment (Figure 48D). After 67 days CH_4 increased and remained high (over 20%) for the remainder of the study. Oxygen levels decreased at that time dropping to a minimum of 2% on the 104th day. Conversely, carbon dioxide increased during the same period. These conditions indicated anaerobiosis which reduces root penetration and plant growth. As in the previous treatment, these conditions inhibit nitrification and enhance denitrification.

Plant Growth

There was some difficulty in obtaining good growth of corn in the trench simulation boxes. Apparently fertility levels were not high enough in the top 30 cm of soil of each box. Nonetheless, plant responses to the control and different sludge treatments should be comparable. The data on plant height and stem diameter (87 days growth) are shown in Table 49. Plants growing in the control were tallest. Plants growing in the digested sludge treatments were next in height, and plants growing in the raw sludge treatments were shortest. The lime additions did not influence the height attained by the plants. There also were no significant effects of sludge or lime treatment on stem diameter.

Roots of corn plants growing in the control were fine textured and they extended throughout the soil (Figure 49). Roots in the digested treatments

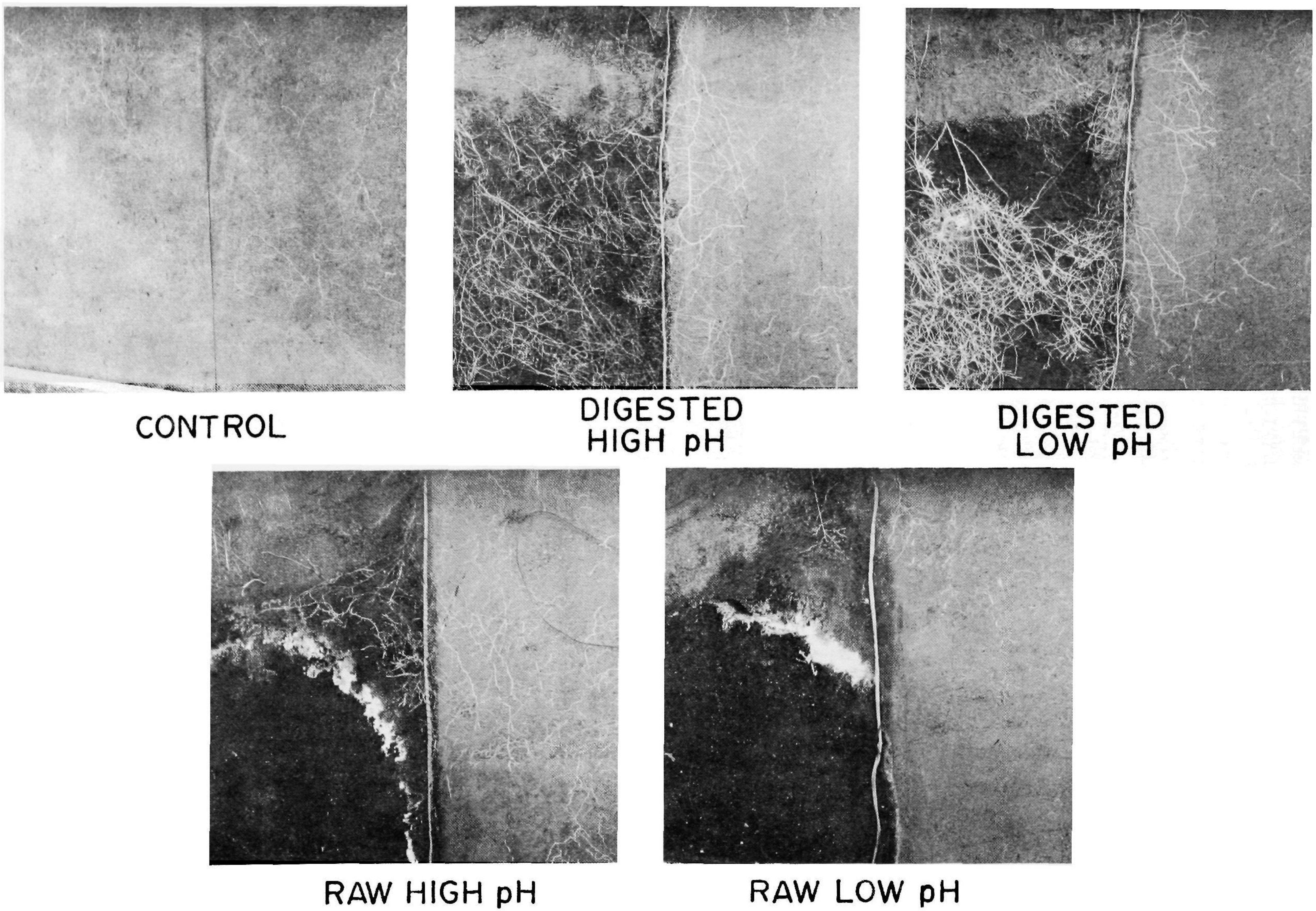


Figure 49. Photographs of root distribution in trench simulation boxes after 98 days.

ultimately penetrated about 45 cm into the digested sludge and extended throughout the soil beside the sludge (Figure 49). Roots seemed to be a little larger in the soil beside the sludge than in the soil further away and also larger than in the control because of responses to nutrients from the sludge. Corn root distribution was apparently more uniform in the high than in the low lime-treated digested sludge. The sludge was dewatered and lighter in color where roots had penetrated.

There was little root penetration into raw sludge even after over 3 months (Figure 49), and most of the raw sludge changed very little in appearance. Characteristically, however, a white fungal growth started at the interface between the soil and both raw sludges and moved with time into the sludges. After passage of this white fungal front, roots were able to penetrate short distances into the sludge where dewatering and change in appearance of the sludge occurred.

Roots did not grow into the soil beside the trenched raw sludge, probably because of rather high concentrations of toxic materials like ammonium (Figure 46) and methane and because of low concentrations of oxygen (Figures 48C and D). Root growth seemed more advanced in the high than low lime treated raw sludge and in the soil beside the sludge. The lime apparently altered somewhat the toxic effects of materials like ammonium and methane (Figures 46, 48C, and 48D).

Thirty-three different fungi were isolated from the sludge boxes. Four fungi are believed to be responsible for the formation of the fungal mantel between the sludge and corn roots. These are *Trichoderma kining*: Oud., *T. lignorum* (Tode) Harz., *Gymnoascus* sp., and *Cunninglamella elegans* Lindner.

Salmonella, Total Coliform, and Fecal Coliform Bacteria

Before incorporation in the trench boxes, the sludges were analyzed for salmonella, total coliform and fecal coliform bacteria. The low pH digested and raw sludges contained many fold higher numbers of fecal and total coliform bacteria than did the high pH digested and raw sludges. No salmonellae were found in the high pH sludges, but they were present in both the low pH sludges (Table 50).

Results of the bacterial analyses of the trench box profiles at the end of the study are shown in Figures 50 and 51. All samples were analyzed for total and fecal coliforms. Only samples taken from the sludge trenches and soil directly above and below the sludge trenches were analyzed for salmonellae. No salmonellae were found. The total and fecal coliform numbers relative to their initial numbers were drastically reduced in the low pH digested and raw sludges. At the beginning, the high pH raw and digested sludge contained only a few total coliforms. The numbers at the end were not significantly changed. Although the fecal coliforms were below the detectable limit at the beginning for both the high pH raw and digested sludges, they continued to multiply

Table 50. MOST PROBABLE NUMBER (MPN) OF SALMONELLA, TOTAL COLIFORM AND FECAL COLIFORM BACTERIA IN SLUDGES USED FOR GREENHOUSE TRENCH SIMULATION BOX STUDIES

Sludge type	Replicate determinations, MPN/g dry weight		
	Salmonellae	Total coliforms	Fecal coliforms
Digested high pH	<15	5	<1
	<14	160	<10
Digested low pH	46	1.8×10^6	3.1×10^5
	<15	3.1×10^6	$<1.2 \times 10^5$
Raw high pH	<15	56	<1
	<16	3	<1
Raw low pH	2600	8.9×10^8	6.1×10^7
	6100	3.5×10^8	7.3×10^7

and were detected in the high pH raw sludge after 161 days at harvest. These results indicate their survival ability despite the high rate of lime application.

More total and fecal coliform bacteria were found in the soil external to the raw high and low pH sludge trenches than in the soil external to the two digested sludge trenches. The greatest numbers were found in the soil external to the high pH raw sludge trench despite the fact that this sludge contained the lowest numbers at the initiation of the study. Coliforms were present in samples taken above the trenches of all the sludge treatments (Figure 50 and 51). They may have moved upward by capillary action and then grown on organic material present in the surface soil.

Downward and lateral movement and subsequent survival of total and fecal coliforms were apparent only in the raw-sludge trench simulation boxes. This occurred possibly because more substrate, as indicated by the total nitrogen concentrations in these areas (Figure 44), moved out from the raw sludges than was available for movement from the digested sludge.

Using coliforms as indicators, it seems apparent that survival of pathogens can occur in the sludge and in the soil adjacent to the sludge trenches for a period of at least 5 months (the duration of this study). Coliform organisms have the ability to reproduce outside their hosts as do apparently the shigellae and the salmonellae. Coliforms are reasonable indicators for organisms of this type. Many pathogens, however,

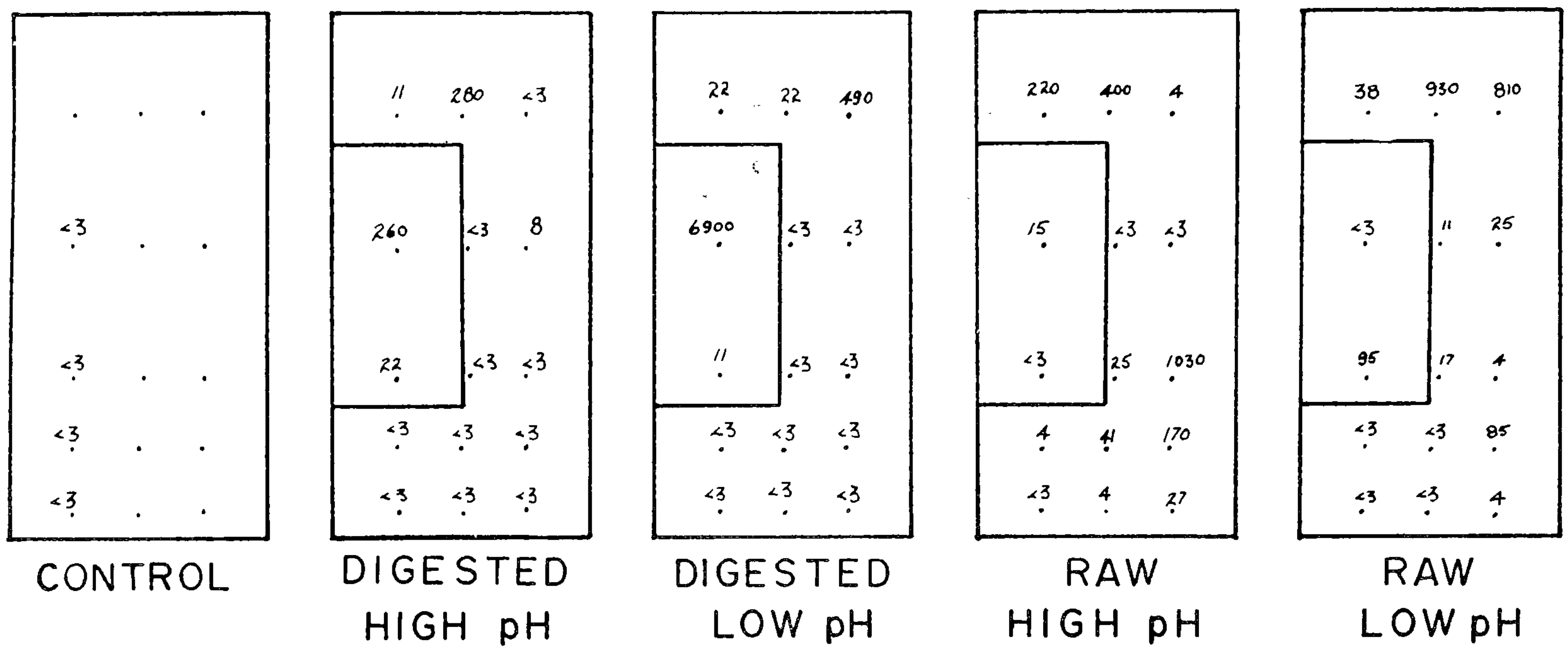


Figure 50. The MPN/g dry weight of total coliform bacteria in trench simulation boxes after 161 days.

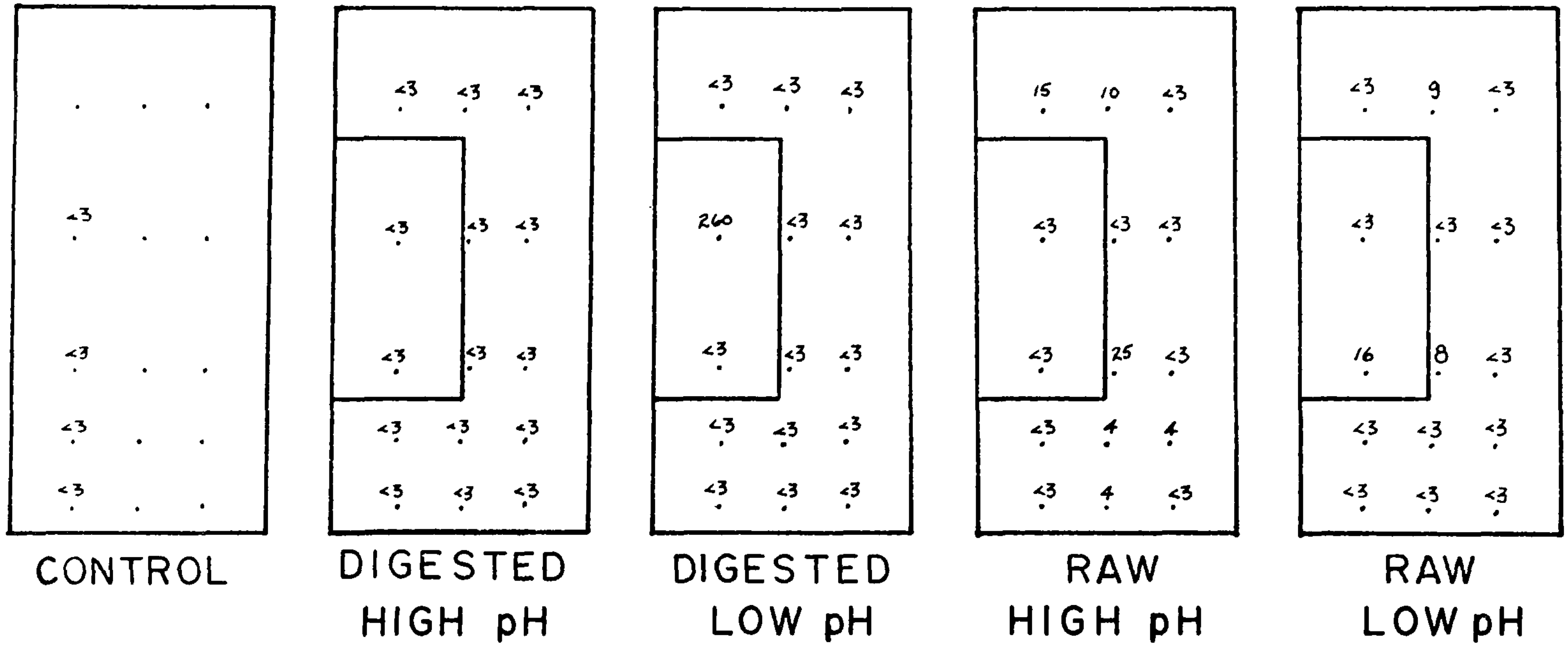


Figure 51. The MPN/g dry weight of fecal coliform bacteria in trench simulation boxes after 161 days.

cannot reproduce outside their human hosts, and determining survival of coliforms as an indicator of their survival is an extremely conservative procedure.

Heavy Metals

Zinc and copper distribution in the trench simulation boxes after 161 days at harvest is shown in Figures 52 and 53. It is clear from the data that neither zinc nor copper moved to any appreciable extent from the sludge section of the boxes into the soils. The large differences of over 500 ppm zinc vs. less than 1 ppm zinc in contiguous samples is very positive demonstration that DTPA-TEA chelate extractable metals did not move. The question then remains, "Why did the metals fail to move from the trench area of the profile?" At least two possibilities exist: (1) lack of water movement through the sludge zones which might have caused a movement of soluble metal or a mass flow of organics that held chelated metals and (2) retention of metals in the sludge area, even if leaching occurred, because of strong chemical binding by the unsaturated cation exchange/chelation capacity of the sludge organic matter under the neutral to alkaline conditions (Figure 47).

We believe that there was some movement of organic materials from the sludge out into the surrounding soil. If gross movement of organic matter occurred, these metals bound to the organic matter should also have moved. If movement occurred, a gradient in metal concentration should then be present. This was not observed. Apparently the near neutral to alkaline conditions prevented the movement of metals with the organic materials.

In other published experiments involving additions of heavy metal salts to soils, usually little or no leaching of metals is reported. Where leaching is reported, a gradient in metal concentration had always been observed in the short-term. When both sludge and heavy metals are present as in our studies, the tests suggest that metal leaching does not occur unless there is a gross movement of organic metal-binding chelates because of (1) the high capacity of the sludge to hold metals against leaching many times in excess of the metals contained in the sludge, and (2) the soil and sludge were not sufficiently acid to cause metal release from the chelation sites and negatively charged surfaces in the sludge. In the trench simulation studies the sludges did not become acidic even after 161 days (Figure 47).

As organic sludges decompose, metals should be released from chelation sites, and some exchange sites will be destroyed. Movement and u[illegible] of these metals by plants might be enhanced, particularly if the soil is acidic. While the soil was acidic the sludges were not and the metals apparently remain bound in the sludge. The metals also may have become bound to inorganic exchange sites in the soil or chemically precipitated as carbonates and phosphates, reducing their ability to move and be absorbed by plant roots.

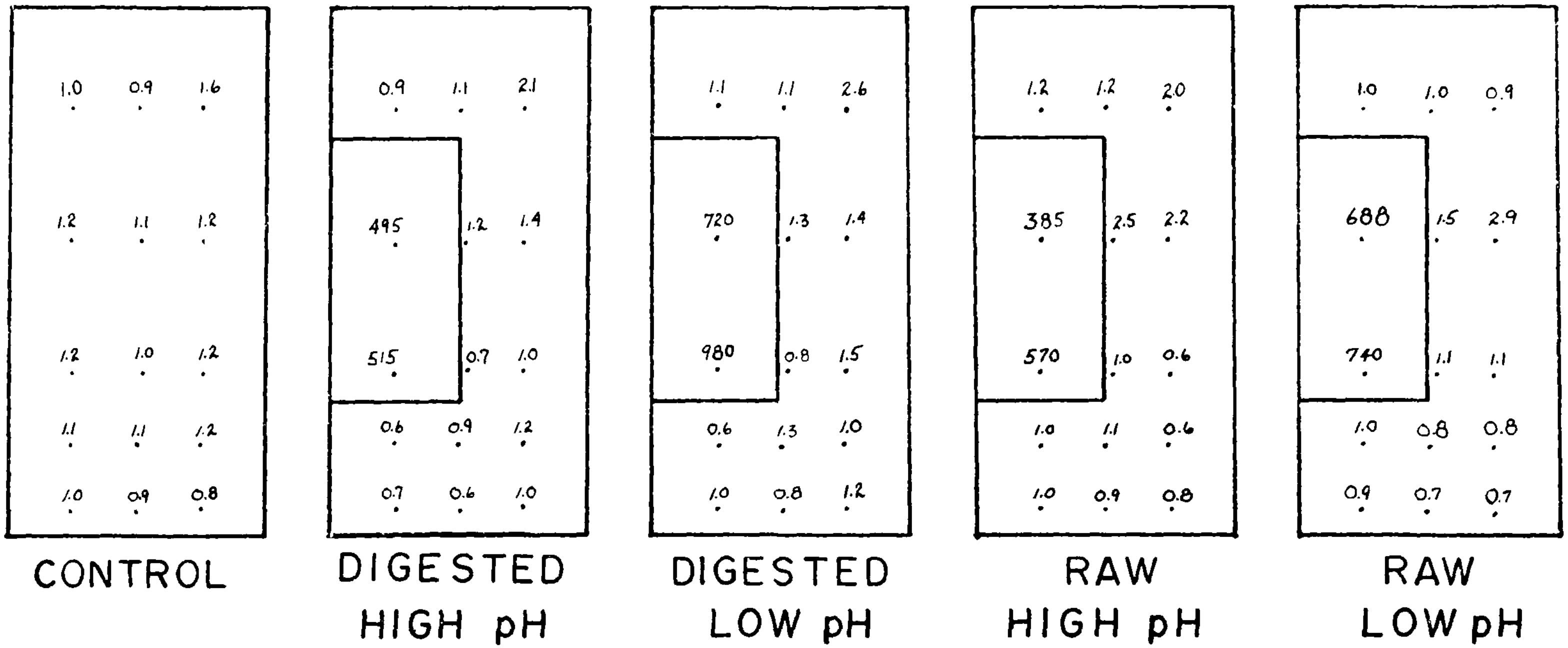


Figure 52. Zinc distribution (DTPA-TEA extractable, μg Zn/g dry soil or sludge) in trench simulation boxes after 161 days.

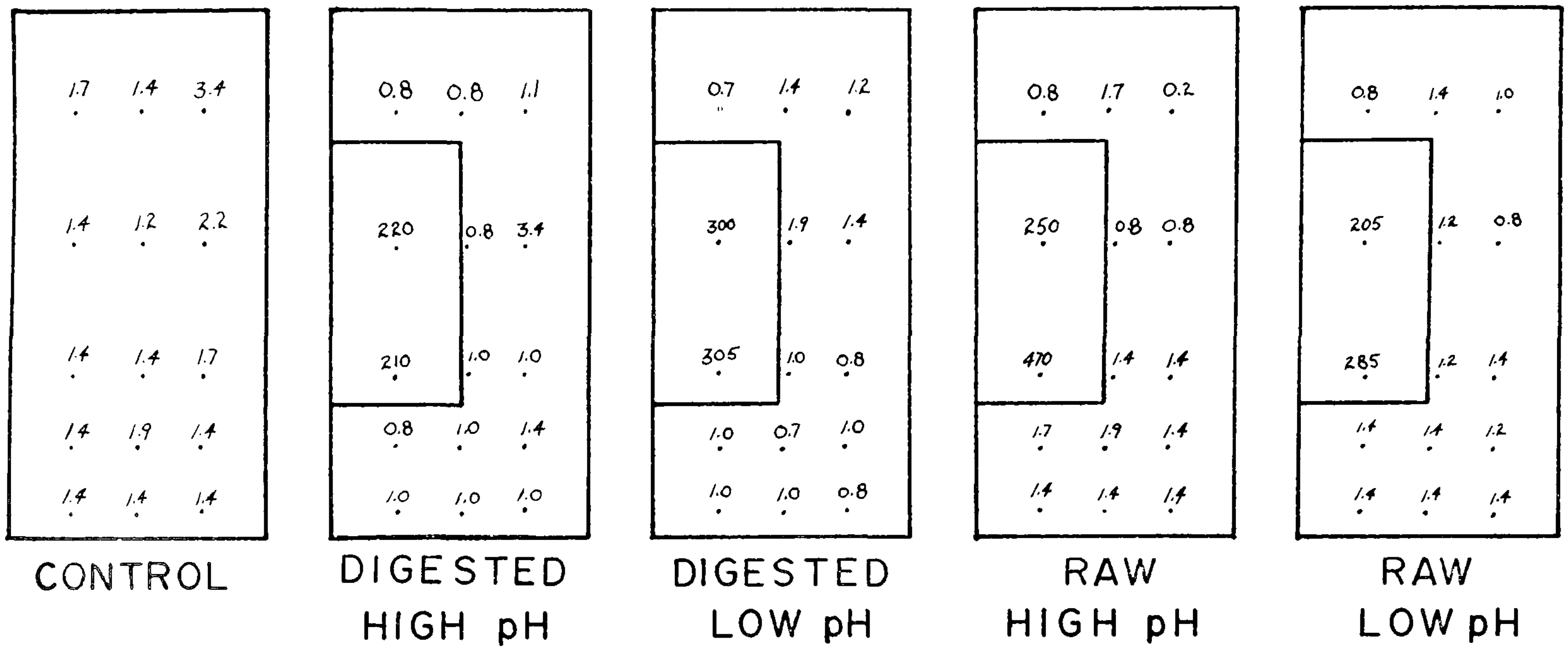


Figure 53. Copper distribution (DTPA-TEA extractable, μg Cu/g dry soil or sludge) in trench simulation boxes after 161 days.

CONCLUSIONS - EXPERIMENT 2

As in Experiment 1, the presence of nitrate under digested sludge and ammonium under raw sludge indicated that measures would probably be needed in the field to provide for capture, retention, and recycling of infiltrating rain water. There was less nitrification and/or greater denitrification associated with the more anaerobic conditions under and within raw than digested entrenched sludge. Hence, there will probably be less initial danger of movement of nitrate from raw than from digested sludge.

Liming sludges to a high initial pH may ultimately insure that the sludge and perhaps the soil pH is buffered against a pH decrease caused by acidity produced by nitrification and possibly other microbial activity. Liming the sludges did not increase nitrate production as might have been expected.

Liming sludges to a high initial pH reduces pathogens to low levels, but does not prevent multiplication of the few surviving microorganisms like fecal coliform and salmonella which have the ability to reproduce outside their human host. There was little movement of total coliform bacteria and even less movement of fecal coliform bacteria. Movement that did occur was not related to sludge lime level.

Since movement of heavy metals did not occur from either limed or unlimed sludge, additional long-term research is needed with more soil types under more widely ranging conditions to determine if liming is helpful in preventing metal movement. Additional research is also needed to determine if liming entrenched sludge will reduce uptake of metals by plants. Adequate determination could not be made in the rather poor crop growth in Experiment 2.

More research will be needed to determine if liming entrenched sludge is really necessary. It does no harm, and reason and theory suggests that it should be beneficial in reducing metal movement in soil and uptake by plants. Therefore, liming sludges prior to entrenchment will probably be important and beneficial in maintaining an equilibrium pH in sludge of 6.5 or greater.

SECTION VII

VIRUS TRANSPORT THROUGH SOIL

INTRODUCTION

The nature of the interaction of viruses and soil is poorly understood. Viruses are amphoteric and are negatively charged within the pH range of most soils. Since the ion exchange complex is predominately negatively charged, viruses like anions of salts might be expected to readily move with a water front through most soils. Studies, however, have shown that viruses are sorbed by soils. The mechanism of sorption has not been determined, however, and the present state of knowledge does not allow the prediction of how far viruses may move with water in any particular soil. The objective of this study was to determine the potential for movement of viruses through a sandy soil leached with water. This study provided a model for evaluating the possible movement of sludge applied viruses into groundwater at trenching sites.

PROCEDURES

Three soil column studies were run to determine the potential for virus movement in the Galestown-Evesboro soil obtained from the trenching site. The bacteriophage of the plant pathogen *Xanthomonas pruni* and attenuated poliovirus type 1, Brunite strain were tagged with radioactive phosphorus to facilitate their monitoring through these soil columns leached with water. The viruses were tagged by introduction of P-32 labeled phosphate into their hosts as substrate during culture previous to infection with the viruses.

Compared to the spherical polio virus' diameter of approximately 230^{o}A, the bacteriophage is relatively large having a hexagonal shaped head 600^{o}A from side to side and overall length of 1,580^{o} A including the head, neck, and 6 tail spikes. During radioactivity assay, plaque forming tests were always carried out to ensure accurate virus:radioactivity ratios. Assay by radioactivity is less sensitive than by bioassay (plaque counting) but P-32 use seemed to be justifiable because of the ease of measurement made possible.

The soil used in this study was sterilized by 3 to 4 megarads of gamma radiation from a Co-60 source to minimize destruction of the viruses by microbial decomposition. The pore volume of water in the columns was determined by measuring the gain in weight of the columns under the flow conditions in the experiments. In all column studies distilled water was applied at the rate of moderate rainfall, 1 cm/hour.

For the first study, 4.0×10^7 plaque forming units (pfu) of *X. pruni* bacteriophage were applied to the top of an air-dry soil column 8.5 cm in length before leaching. In the second study, poliovirus was introduced in solution to the top of an air-dry column of soil 150 cm long before leaching. In the final study, soil columns each 8.5 cm long were leached with water, then each column was leached with a different concentration of poliovirus as suspended in 0.08 ionic strength Dulbecco's buffer. The virus concentrations were 4.0×10^5 and 4.0×10^6 pfu/ml.

RESULTS

When the bacteriophage was applied to the top of an 8.6 cm long column of soil and leached at a rate of 1 cm/hour, about 76% of the virus was removed from the column in the first 30 ml (1.43 pore volumes) of leachate (Figure 54). Of the 24% sorbed, the highest concentration occurred in the first 5 mm of column depth (Figure 55). The amount of rainfall (R) needed to move this virus peak any depth can be estimated by use of the two following equations (Swoboda and Thomas 1968, J. Agri., Food & Chem., 16 pp, 923-927):

1) $k = \left(\frac{Vp}{Vv} - 1\right) \frac{Vv}{W}$

Where: k = distribution coefficient
Vp = effluent volume to leach one-half of the virus from the column
Vv = water filled pore volume of column
W = weight of the soil in column

2) $R = L\left(kp + \frac{Vv}{V}\right)$

Where: L = depth virus will be moved
p = bulk density of the soil
V = total volume of the soil filled portion of column

The Vp in the first equation is determined by use of a wet column rather than an air-dry one as was the case in this experiment. Assuming peak symmetry, which admittedly can be erroneous, and accounting for the displaced pore volume, Vp was estimated at 30 cm. The amount of rainfall calculated to move the virus 150 cm (5 feet) was 83 cm (33 inches).

To check the validity of the use of short columns as a model for longer columns, a 150 cm long air-dry column was packed. At this time, radioactively tagged poliovirus became available. The virus (4×10^7 pfu) was placed on top of the column. Upon leaching with distilled water (1 cm/hr), a band of virus representing 1.3% of the amount applied was eluted from the column after passage of 1.58 pore volumes of water (1,010 ml). The pore volume divided by the inside cross-sectional area of the column indicated that 60 cm (24 inches) of rain would be required to elute the band peak of virus from the column as compared to the 83 cm calculated by use of the small column data. Both the rainfall required for elution and the fraction of virus eluted were smaller than predicted, indicating that a portion of the moving virus band was continually being sorbed and retained by the soil.

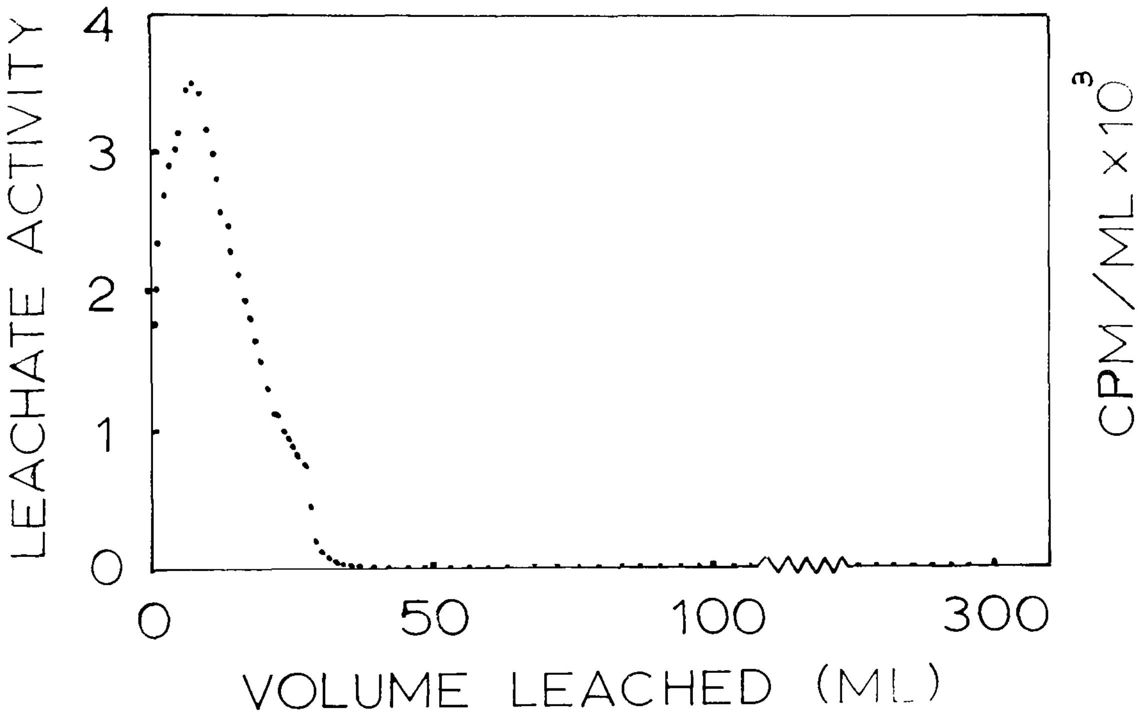


Figure 54. Elution of Xanthomonas pruni bacteriophage from Galestown-Evesboro sandy loam soil. Rate of leaching was 1 cm/hour and the column was 8.5 cm long.

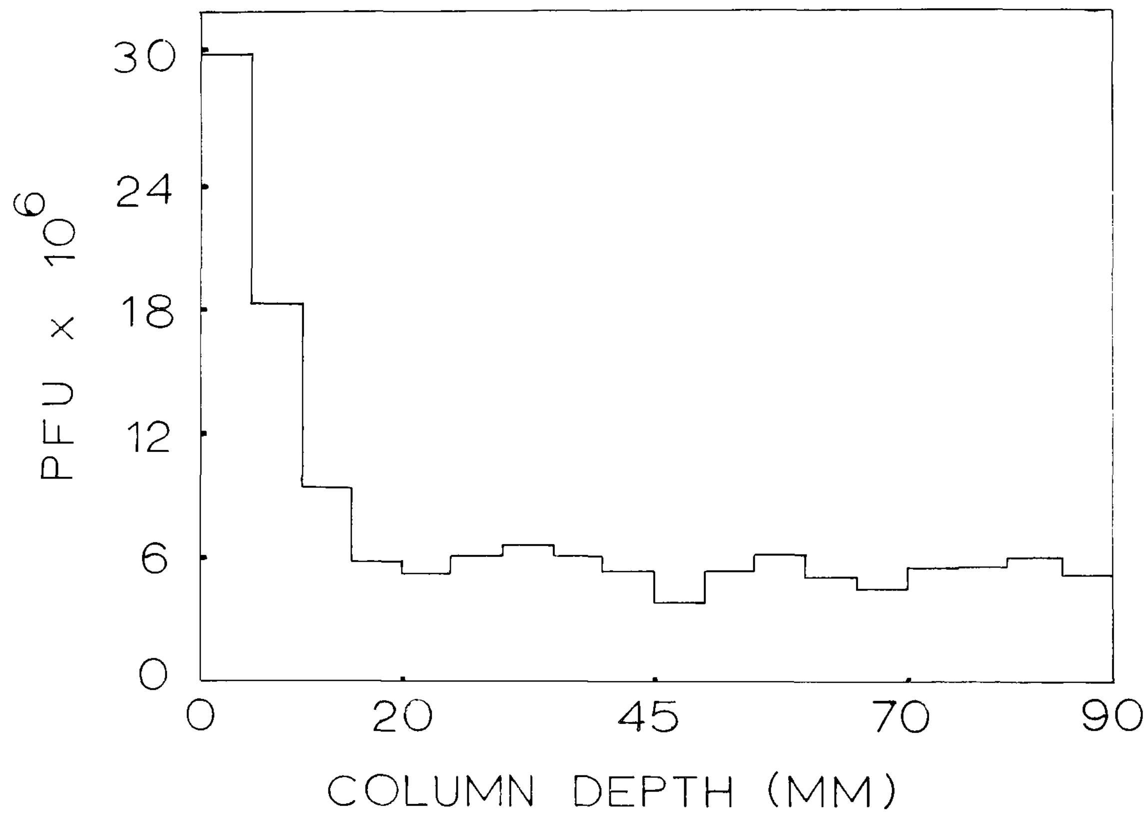


Figure 55. Distribution of Xanthomonas pruni bacteriophage adsorbed on a column of Galestown-Evesboro sandy loam soil after 300 ml leaching at 1 ml per hour.

In the third column study, the objectives were to compare the movement of poliovirus with the electronegative chloride ion and the electropositive sodium ion, to get an estimate of the distribution coefficient (k) in a wet column, and to determine the virus holding capacity of the soil under short column conditions.

Chloride, the least sorbed of the monitored substances, was the quickest to reach an effluent concentration equal to the influent; sodium was next, followed by the virus, which never exceeded 60% of the initial concentration even after 20 pore volumes had leached through (Figure 56). The effluent solution was buffered by the soil at a pH of 4.6 for about 10 pore volumes, then increased to a pH of 6.7, which is approximately that of the buffered influent.

The poliovirus elution curves (Figure 56 and 57) show a sharp decrease in the rate of virus sorption between 175 and 225 ml of effluent. The cause of this decrease is not clearly understood, but it is possible that the soil was dispersed upon sorption of sodium. The dispersion of the soil reduced the flow rate through the column and allowed longer equilibration time for virus sorption. The distribution coefficient could not be calculated from the data because of the lack of uniformity in the curve for the virus front (Figures 56 and 57).

Despite application of more than 13 pore volumes of the virus solution to the soil in the columns, the sorption capacity of the columns were far from being reached. As shown in Figure 58, for the column perfused with the highest poliovirus concentration (4×10^6 pfu/ml), about 55% of the total virus retained was sorbed in the first 5 mm section. For the column perfused with 4×10^5 pfu/ml, 33% was sorbed in the first 5 mm or in 5.9% of the column length.

DISCUSSION

In the short air-dry soil column the bacteriophage swept through with a band peak at 30 ml as corrected for water that would have to be displaced had the column been wet (Figure 54). The minimum amount of eluent to produce a peak of poliovirus from the prewet short column would have been between 140 to 225 ml (Figure 56). A peak in this experiment would be indicated by the curve reaching a plateau. This data seemed to indicate, if virus difference can be ignored, that a large part of the sorption occurred in the soil on some component that was not readily wetted, possibly organic matter. The high concentrations of viruses sorbed in the upper portions of the column indicated that the sorption process involved time. The time requirement also pointed toward the involvement of organic matter, since sorption in an organic matter matrix is controlled by the rate of diffusion and requires time as opposed to the instantaneous processes expected to occur on soil mineral surfaces. Intermicellular dimensions of clays are too small for virus diffusion. Sesquioxide gels in the soil must be considered as sorptive sites because they also contain positive charges for sorption of the negative virus and have been shown to be involved in

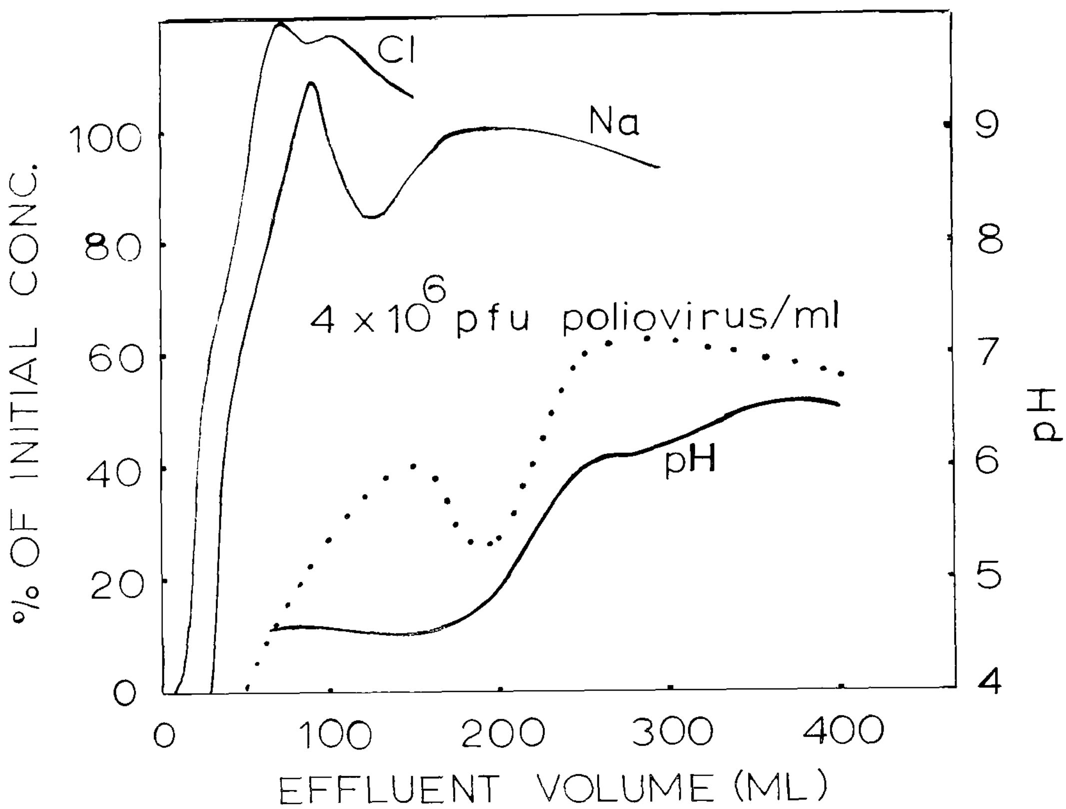


Figure 56. Elution of poliovirus from Galestown-Evesboro sandy loam soil. Chloride and sodium ion concentrations of effluent are also presented. Rate of leaching was 1 cm per hour. The column was 150 cm long.

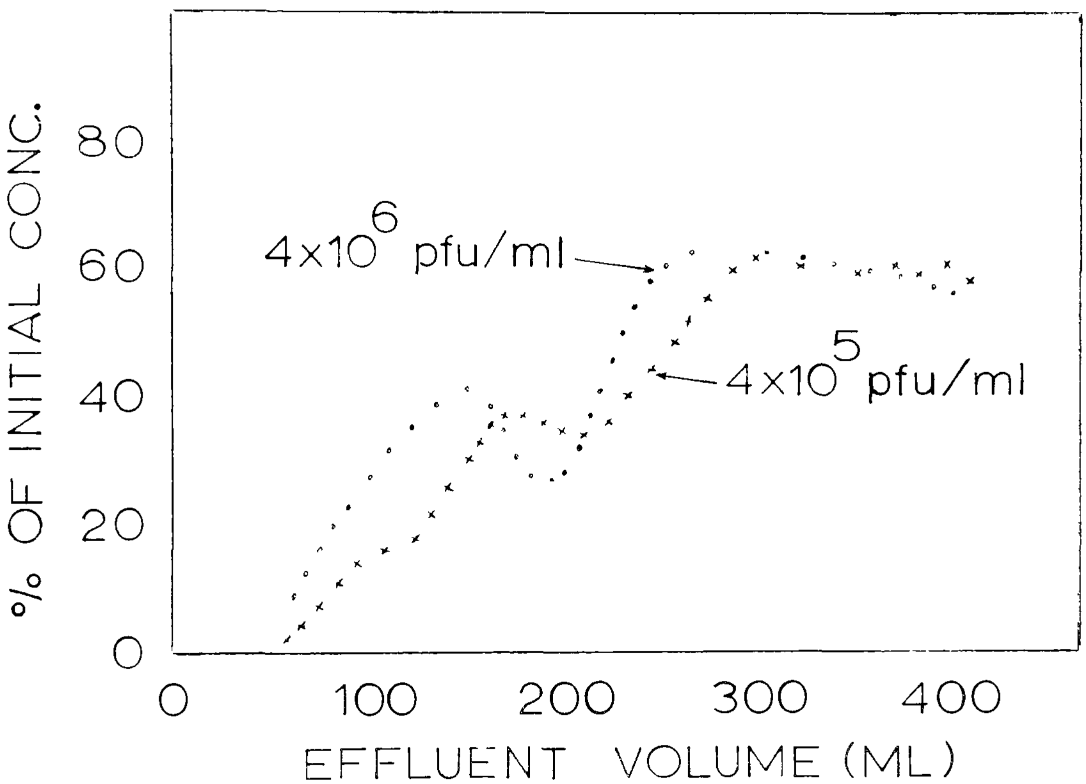


Figure 57. Comparison of elution curves of poliovirus supplied continuously (1 cm per hour) at two concentrations to columns of Galestown-Evesboro sandy loam soil. Columns were 8.5 cm long.

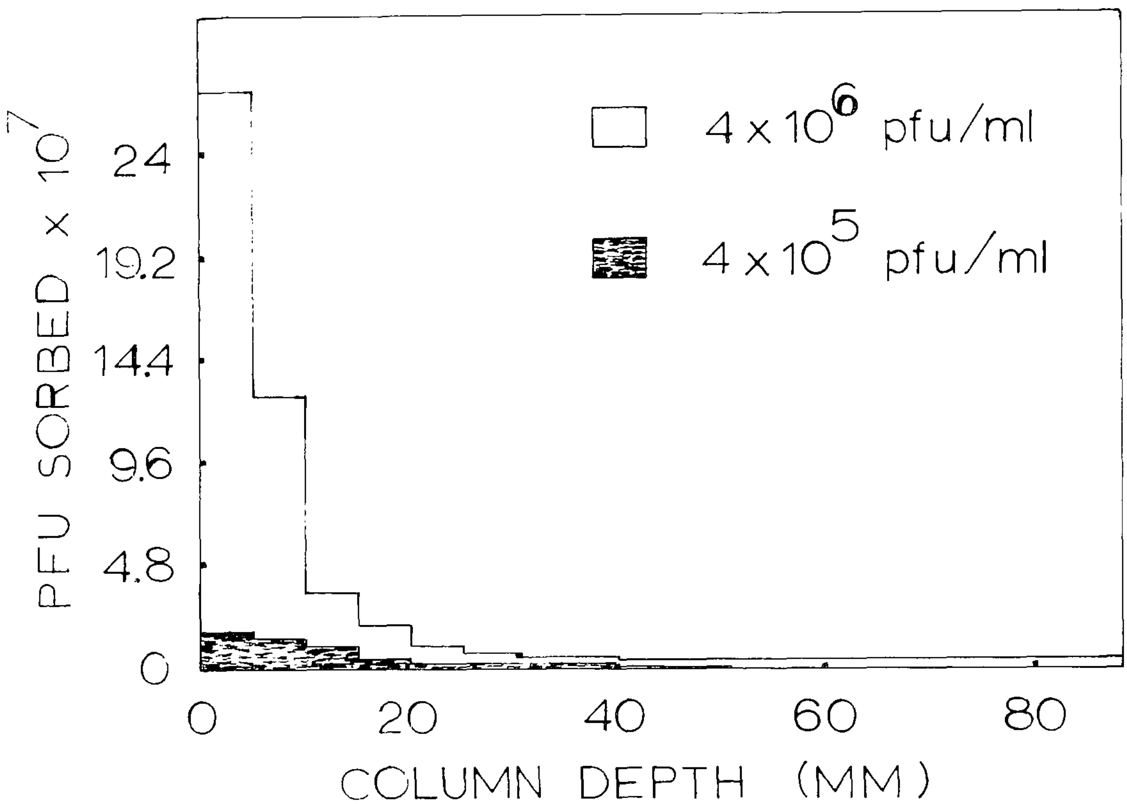


Figure 58. Distribution of poliovirus adsorbed with depth of columns of Galestown-Evesboro sandy loam soil after applying continusouly in the influent of two concentrations of poliovirus for 400 hours at 1 cm per hour.

diffusion controlled sorption. More studies of instantaneous and diffusion controlled sorption processes in soil are needed.

The long column study indicates that even in the air-dry coarse textured soil, 60 cm (24 inches) of rain would be required to move the virus to a water table 150 cm (5 feet) of depth. A rainstorm of this size (60 cm) is a rare event. Disregarding the upward movement of water by capillarity and evaporation at the soil surface, this volume of water coming in increments in 1 to 6 cm storms would not be expected to move the virus to a 150-cm deep water table. Between storms the virus solution would have time to equilibrate with the soil with more of the virus becoming sorbed at each stepwise movement. Therefore, it seems that in any normal rainfall sequence it would be very unlikely that a virus, even in as coarse a textured soil as this one, would be capable of reaching the groundwater. The continued persistence of the virus in an infective state so that it would be subjected to an entire year's rainfall seems unlikely. Further, if the virus did reach the water table, lateral movement of the water table through strata should provide further change for capture of the virus by sorptive surfaces.

Finally, the study was performed in a relatively coarse textured soil. Location of trenching or surface incorporation sites on finer textured soil should lower considerably any potential for the virus to move into the groundwater through the soil profile. It must be recognized, however, that only a few soils have been examined for their ability to sorb viruses and as yet the process is not well understood. A much better understanding of the sorption process as influenced by various soil factors is needed.

SECTION VIII

HEAVY METALS

ANALYSES OF BLUE PLAINS SEWAGE SLUDGES

A cooperative program of sampling and heavy metal analyses was undertaken with the Blue Plains Wastewater Treatment Plant and the EPA-DC Pilot Plant. The objective was to determine the sludge metal and nutrient content for a period of one month. Raw primary and digested combined primary plus secondary sludge came from Blue Plains and raw alum-secondary sludge came from the Pilot Plant. Subsequently, sludges of different types from Blue Plains have been analyzed on a periodic basis to ascertain variation in metal content over a longer period of time and to learn more about the effect of wastewater and sludge treatment on sludge metal content.

Procedures

The first set of sludge samples were daily 24-hour composites from the period February 8 to March 9, 1972. The second set of samples were composites of digested sludges limed to different pH's in July 1972 for the pH study described in Section V. The third set of samples were of sludges produced at Blue Plains in April 1974.

The sludge samples were dried at 60°C, ground, and dry ashed at 500°C. The ash was treated with concentrated HNO_3, again heated to dryness, and then dissolved in 6 N HCl on a steam plate. The ash solutions were filtered (Whatman #42), diluted to volume, and analyzed by atomic absorption spectophotometry (for Ca, Cd, Cu, Mg, Ni, Pb, and Zn), flame photometry (for Na and K), or colorimetry (for P). Samples were analyzed in duplicate unless otherwise stated. The drying oven overheated and ruined most sludge samples in the first series taken after February 14. Background subtraction was not used in analyses of Cd, Ni, and Pb on the samples taken during early 1972.

Results

February-March 1972 -- The results are shown in Table 51. Note the small day to day variation in content of most elements. Most elements were more concentrated in digested than raw sludges because of biological degradation of the organic fraction and resulting concentration of the inorganic fraction. Potassium is water soluble and did not increase during the digestion process.

The digested sludge was a combination of approximately three parts primary to two parts secondary waste activated sludge. Hence, the resultant metal concentrations are a mean of the metal contents of the two components, which in turn are concentrated by digestion.

Table 51. ANALYSES* OF BLUE PLAINS SLUDGES, FEBRUARY 8-14, 1972

Date		Dry wt %	% dry sludge				Metals, mg/kg dry sludge				
			P	K	Ca	Mg	Zn	Cu	Ni **	Pb **	Cd **
Raw primary - Blue Plains											
Feb	8	0.78	0.70	0.19	1.38	0.19	740	550	92	140	29
	9	0.82	0.73	0.24	1.36	0.20	710	460	102	120	30
	10	0.86	0.71	0.23	1.41	0.22	800	380	114	170	33
	11	1.08	0.63	0.19	1.32	0.21	750	320	87	220	29
	12	0.78	0.68	0.21	1.39	0.24	720	450	81	110	26
	13	0.80	0.69	0.19	1.26	0.22	710	220	101	240	26
	14	1.20	0.75	0.22	1.36	0.24	760	300	100	290	35
Mean			0.70	0.21	1.35	0.22	740	380	97	180	30
Raw alum-secondary - pilot plant											
Feb	8	1.35	4.20	0.17	1.70	0.21	910	320	34	170	10
	9	1.54	3.74	0.17	1.46	0.19	880	300	30	160	10
	10	1.54	3.94	0.18	1.44	0.19	920	310	30	150	10
	11	1.55	4.25	0.18	1.41	0.20	940	330	26	180	10
	12	1.27	4.10	0.17	1.49	0.21	990	320	26	180	10
	13	0.76	3.94	0.19	1.38	0.21	870	280	26	210	10
	14	1.75	4.06	0.20	1.31	0.22	820	290	27	250	11
Mean			4.03	0.18	1.46	0.21	900	310	28	190	10

Continued

Table 51 (continued). ANALYSES* OF BLUE PLAINS SLUDGES, FEBRUARY 8-14, 1972

Digested - Blue Plains										
Feb 8	21.8	1.64	0.17	2.46	0.39	1800	730	72	640	21
9	22.4	1.58	0.16	2.40	0.38	1760	670	62	640	20
10	20.7	1.70	0.16	2.40	0.39	1810	680	66	600	20
11	23.1	1.65	0.15	2.40	0.36	1800	680	68	620	20
12	22.8	1.73	0.15	2.37	0.36	1860	700	66	590	20
13	22.5	1.75	0.15	2.46	0.37	1820	690	71	560	20
14	23.0	1.78	0.16	2.45	0.37	1890	720	70	570	20
Mean		1.69	0.16	2.42	0.38	1820	700	68	600	20

* All values are mean of replicate analyses.

** No background subtraction.

The secondary sludge component of the digested sludge analyzed in Table 51, however, was not alum-treated. Hence, the digested sludge metal contents shown in Table 51 are not a mean of the raw primary and secondary-alum treated sludges (with allowance for digestion).

The high phosphate concentration of raw alum-secondary sludge resulted because the alum chemically precipitated the phosphate from the wastewater. Nickel and cadmium levels were not comparable between sludges because background subtraction was not used. The Ni and Cd values are not absolute and are only meaningful to determine day to day variation in metal within a sludge type.

July 1972 -- The results are given in Table 52. Metal concentrations were slightly lower as the lime content increased. The lime which was added just prior to dewatering increased the mass of sludge; however since the lime did not contact treatment plant wastewater, additional metals were not removed. The final lime content in the sludge was lower than the initial amount of lime added at the plant because some lime was lost in dewatering.

April 1974 -- Metal concentrations in all different types of sludges produced at Blue Plains on one day are given in Table 53. There is no significant difference in metal content in the raw primary, raw secondary, or combined raw primary and raw secondary sludges. The metal concentrations are about twice as high in the digested as in the raw sludge because of mass reduction by biological decomposition of organic matter.

The variability in metal content of digested sludges sampled from 12 different truckloads of sludges produced over 4 days are also given in Table 53. In some cases the range in metal content is larger than half of the mean values.

Long Term Variability -- There is also considerable variability in elemental contents of sludge over the long run (Table 54). Systematic sampling of each type of sludge at a treatment plant over a several year period is important for determining extent of variability in sludge metal content, source of metal pollutant, extent of sludge digestion, effect of chemical treatment, etc.

ANALYSES OF OTHER SLUDGES

A survey of Washington area wastewater treatment plant sludges was conducted during late 1972 and early 1973 to compare these to Blue Plains sludge. These results are presented in Table 55. Analyses were also made of sludges from other towns and cities in the United States (Table 56). These analyses show that the variation among sludges is quite great and that extreme concentrations of heavy metals occur in some sludges (largely industrial cities), while sludges from clearly domestic sources are usually quite low in metals.

Table 52. ANALYSES OF BLUE PLAINS SLUDGE AS INFLUENCED BY LIME*

Date Prepared	pH**		Rate added as % of dry sludge**		Metals, mg/kg dry sludge			
	Jul 1972	Oct 1973	Lime	$FeCl_3$	Zn	Cu	Ni+	Cd+
7/18/72	5.8	6.5	0	2.2	1690	710	91	13.8
7/21/72	10.5	7.2	4.6	0.3	1650	660	73	12.8
7/20/72	12.3	9.6	13.6	7.0	1500	590	119	10.8

* Samples July 1972, stored, and analyzed October 1973.

** See also Table 39.

\+ Corrected by background subtraction.

Table 53. ANALYSES OF BLUE PLAINS SLUDGES, APRIL 1974

Sludge type	Composite of	Date	% Solids	Metals, mg/kg oven dry solids Zn	Cu	Ni*	Cd*	Pb
Liquid, not elutriated								
Raw primary	24**	4/1-4/2/74	2.3	916	340	33	8	380
Raw secondary waste-activated ($FeCl_3$)	24**	4/1-4/2/74	4.2	1004	290	33	9	370
Raw thickend primary plus secondary ($FeCl_3$)	24**	4/1-4/2/74	10.7	1210	290	39	9	490
	Mean			1040	310	35	9	410
Digested	24**	4/1-4/2/74	3.3	2480	670	50	26	780
Elutriated, dewatered, digested +								
		4/2/74	25	2570	710	47	25	810
		4/2/74	22	2520	710	48	26	810
		4/2/74	25	2290	660	44	24	790
		4/3/74	25	2330	670	44	24	770
		4/3/74	24	2330	670	45	24	770
		4/3/74	22	2940	820	58	30	980
		4/3/74	25	2320	650	44	22	760
		4/4/74	26	2220	620	42	21	720
		4/4/74	25	2350	680	45	23	760
		4/4/74	26	2370	670	46	23	770
		4/4/74	25	2320	630	44	23	740
		4/5/74	28	1560	440	43	22	520
	Mean		25	2340	660	46	24	770

* Corrected by background subtraction.

** Twenty-four hourly grab samples composited into one sample.

\+ Samples taken from separate truck loads of sludge hauled to the Beltsville composting site.

Table 54. MEAN ELEMENTAL CONTENTS OF BLUE PLAINS SLUDGE

Date	% dry solids					Metals, mg/kg dry solids				
	N	P	K	Ca	Mg	Zn	Cu	Ni	Cd	Pb
<u>Digested combined primary and secondary</u>										
Feb 1972	-	1.7	0.2	2.4	0.4	1820	700	68*	20*	600
May 1972	2.5	1.1	0.5	1.6	0.1	2010	720	-	-	-
Jul 1972	-	-	-	-	-	1610	650	94	13	-
Apr 1974	-	-	-	-	-	2340	660	46	24	770
<u>Raw combined primary and secondary</u>										
Feb 1972	-	2.4	0.2	1.4	0.2	820	340	62*	20*	180
Apr 1974	-	-	-	-	-	1040	310	35	9	410

* Background subtraction correction not made on cited numbers only.

Table 55. HEAVY METAL CONTENTS OF WASHINGTON AREA WASTEWATER TREATMENT PLANT SLUDGES

	Type*	Zn	Cu	Ni	Cd	Pb
		mg/kg dry sludge				
Fairfax County						
Lower Potomac	R	370	210	60	2	120
Westgate	R	660	380	30	<11**	-
Hunting Creek	R	230	250	15	<1	-
Hunting Creek	D	580	370	25	4	-
Dogue Creek	R	290	170	30	<9**	-
Arlington County	D	1700	1640	65	18	360
Alexandria	R	1030	730	25	17	280
Prince William County						
Belmont	D(A)	550	150	15	4	160
Neabsco	D(A)	740	520	20	5	120
Featherstone	D(A)	430	250	15	3	160
Occoquan	D(A)	440	190	10	2	60
WSSC						
Piscataway	D	600	350	35	5	300
Parkway	D	1320	500	50	16	700
Western Branch	D	960	260	40	10	140
Washington, D.C.						
Blue Plains	D	1610	650	80	12	540
MES Compost	D,C	1140	350	330	9	310

* R = raw; D= anaerobically digested; D(A) = aerobically digested; D,C = composted digested; WA = waste activated.

** Background subtraction not used on cited numbers only.

PLANT GROWTH STUDIES

A series of plant growth studies were undertaken. Effects of metals on plant growth were compared when added in equivalent amounts as sludge or as metal salts. A number of different crops were grown because of their suspected different tolerances to given levels of heavy metals in soils. Two lime ($CaCO_3$) levels were included because of the dominating effect of soil pH on metal availability to plants.

Table 56. HEAVY METAL CONTENT OF VARIOUS SEWAGE SLUDGES

	Type*	Zn	Cu	Ni	Cd	Pb
			mg/kg dry sludge			
Maryland						
Baltimore	D	4970	2100	340	20	-
Hagerstown	D	1500	980	40	10	400
Frederick	R	880	680	100	615	490
Cumberland	D	1330	640	20	15	
Westernport	D	360	130	60	2	
Others						
Corning, New York		1250	420	40	7	480
Ervin, New York		1210	450	40	10	140
L.A. County "Nitrohumus"	D	2200	730	140	20	-
Grand Rapids, MI	D	20500	3140	3870	165	-
Philadelphia, PA SW (3)	D	2800	800	110	30	-
Fostoria, OH	D	970	16030	120	4	-
Detroit, MI	R	4610	1050	1210	100	
Chicago, WSW	WA	2720	1040	350	235	-
"Milorganite"	WA	1980	500	120	150	-
West Chester, PA	D	730	120	50	2	-
Tiffin, OH	D	4520	831	80	<10**	-
Denver, Colorado		1670	560	220	<20**	-
Miami, Florida	D	1780	500	240	<60**	-
"Tex-Organic"	D	1880	370	20	<15**	-

* D = digested, R = raw, WA = waste activated.

** Background subtraction not used on cited numbers only.

Procedure

Twelve crops listed in Table 57 were grown on each of four treatments: (1) Evesboro loamy sand + NPK (100 ppm N, 100 ppm P, and 126 ppm K); (2) Evesboro loamy sand + 5% Crystal Lake peat + NPK; (3) Evesboro loamy sand + 5% Baltimore digested sludge (adding 186 ppm Zn + 66 ppm Cu) + NPK; and (4) Evesboro loamy sand + metal sulfates adding 186 ppm Zn and 66 ppm Cu + NPK. The mixtures were adjusted to approximately pH 5.5 and 6.5 with $CaCO_3$ and incubated 2 weeks before seeding. There were two replications per treatment. The Baltimore digested sludge was used because it was expected to contain more heavy metals than Blue Plains sludge. The Baltimore sludge was dried at 50°C and ground in a Wiley mill before use.

Table 57. YIELD OF VARIOUS CROPS GROWN IN EVESBORO LOAMY SAND AMENDED WITH BALTIMORE DIGESTED SLUDGE, EQUIVALENT RATES OF ZINC AND COPPER, PEAT, AND FERTILIZER ONLY

Crop	Variety	Dry matter g/pot							
		Control		Peat only		Sludge		Zn, Cu salts	
		pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5
Corn	WF9x38-11	1.40	1.43	2.70	2.49	1.10	1.69	0.79	1.44
Bean	UI-111 Pinto	1.25	1.34	1.39	1.40	0.07	0.72	0.14	0.13
Swiss chard	Fordhook Giant	1.50	1.11	2.32	2.06	0.09	0.46	0	0.67
Soybean	Kent	0.78	0.82	1.60	1.42	0.16	0.73	0.13	0.64
Tomato	Marglobe	0.65	0.54	2.46	2.00	0.30	0.32	0.01	0.47
Mustard	S. Giant Curled	0.48	0.28	1.53	1.50	0.40	0.31	0	0.38
Mustard	Florida Broadleaf	1.45	0.58	2.40	2.50	0.09	0.59	0	0.28
Turnip	Seven Top	1.82	1.02	2.76	2.70	0.14	0.75	0	0.74
Sugarbeet	US H20	1.50	1.09	1.88	1.87	0.10	0.38	0.02	0.67
Wheat	Nugaines	2.26	2.04	2.14	2.00	1.20	1.33	0.48	1.19
Rye	Balbo	1.96	1.98	2.51	2.07	0.76	1.28	0.49	1.41
Fescue	Kentucky-31	1.11	1.00	1.20	0.85	0.42	0.33	0.35	0.35
Seeding pH	May 1	6.50	7.16	6.43	7.18	5.83	7.23	5.90	7.11
Harvest pH	June 1	6.01	6.58	5.95	6.49	5.86	6.34	5.65	6.97

Results

The crops, and mean yields of replicate pots are shown in Table 57. Primary leaves of the bean and soybean were harvested separately and yields not included. The symptoms of injury and yield on both the sludge and Zn + Cu treatments were quite pH dependent. The mustard, turnip, chard, sugarbeet, and tomato were chlorotic at pH 5.5; at pH 6.5 each was stunted, but green. The soybean was extremely stunted at low pH on the Zn and Cu treatments (but remained green), while at the high pH, the plants grew enough to become chlorotic. Growth was not as vigorous as it might have been in all treatments because the soil was found to be somewhat low in magnesium. In addition, growth of crops in the sludge amended soil was reduced because of initial toxic effects of the sludge (salt, low oxygen, and relatively high ammonia). Growth was significantly enhanced in the peat treatment probably as a result of improved soil-water relationships.

Low soil pH had a dominating effect in reducing plant growth when metals were present either as sludge or as salts. Low pH did not reduce growth when metals were present only in trace amounts in the control and in the peat amended soil. A logical conclusion would be, therefore, that the reduction in growth was probably caused by the lower pH which caused increased metal toxicity to the different crops. The soil pH at seeding and harvest are also given in Table 57. While seeding and harvest pH levels were different, differentials between high and low pH treatments were maintained.

The Zn and Cu content of leaves of these crops are shown in Tables 58 and 59, respectively. The soil pH strongly effected Zn contents of leaves for most crops. For a few (chard, rye, wheat, and fescue) this expected result was not observed. The lack of effect may have been caused by the interaction of toxic levels of several metals at the low pH which prevents transport of Zn to the top of the plant. Crops differed widely in both Zn and Cu accumulation (compare chard vs. fescue). The considerably increased metal levels in the crops grown in soils where metals were present and where pH was low would tend to confirm the view that plant growth was being reduced by metal toxicity. It was clear that the Zn and Cu present in sludge-soil mixtures were considerably less available and hence less toxic to plants than the same amount of these metals added as inorganic salts.

The absorption and translocation to plant tops of Cu (and Ni, Pb, and Hg) differs markedly from Zn (and Cd and Mn). Cu is held in the plant roots and may kill a plant from Cu toxicity, even though the plant tops contain less than 100 ppm Cu. Zn is translocated to a much greater extent and a plant dying from Zn toxicity can contain 2000 to 3000 ppm Zn in the tops. Along with these differences in absorption-translocation of Cu and Zn, the content of Zn in plant tops is strongly affected by liming, while Cu content in tops is usually only slightly affected by liming.

Table 58. ZINC CONTENT OF LEAVES OF VARIOUS CROPS GROWN IN EVESBORO LOAMY SAND AMENDED WITH DIGESTED SLUDGE, EQUIVALENT RATES OF ZINC AND COPPER, PEAT, AND FERTILIZER ONLY

Crop	Variety	Zn , μg/g dry weight							
		Control		Peat only		Sludge		Zn, Cu salts	
		pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5
Corn	WF9x38-11	44	40	32	27	655	295	1410	726
Swiss chard	Fordhook Giant	137	31	58	42	1270	1330	-	826
Soybean	Kent	48	43	36	28	444	222	242	471
Tomato	Marglobe	40	38	37	28	628	335	-	158
Mustard	S. Giant Curled	51	22	44	28	1300	660	-	736
Turnip	Seven Top	51	32	34	32	883	650	-	645
Sugarbeet	US H20	57	30	58	41	1369	1193	358	642
Wheat	Nugaines	38	28	32	34	194	272	469	518
Rye	Balbo	38	32	33	34	228	296	899	372
Fescue	Kentucky-31	50	26	37	29	260	301	1037	365

Table 59. COPPER CONTENT OF LEAVES OF VARIOUS CROPS GROWN IN EVESBORO LOAMY SAND AMENDED WITH DIGESTED SLUDGE, EQUIVALENT RATES OF ZINC AND COPPER, PEAT, AND FERTILIZER ONLY

Crop	Variety	Cu, μg/g dry weight							
		Control		Peat only		Sludge		Zn, Cu salts	
		pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5	pH 5.5	pH 6.5
Corn	WF9x38-11	8	9	7	8	25	24	42	36
Swiss chard	Fordhook Giant	14	12	8	10	42	44	-	58
Soybean	Kent	6	4	3	4	10	11	8	22
Tomato	Marglobe	13	12	8	6	22	24	-	29
Mustard	S. Giant Curled	6	6	5	6	67	44	-	57
Turnip	Seven Top	8	7	6	8	88	74	-	100
Sugarbeet	US H20	18	16	10	11	63	44	-	55
Wheat	Nugaines	8	10	9	8	12	12	14	16
Rye	Balbo	7	8	5	8	10	10	10	13
Fescue	Kentucky-31	8	10	10	10	26	32	24	28

The phytotoxicity of Baltimore digested sludge applied at disposal rates on a soil of low cation exchange capacity (1.8 meq/100g by sum of cations) was observed to be substantial and due mostly to Zn, Cu, and B; but for some crops phytotoxicity was apparently due mostly to soluble salts. The pH dependence of toxicity surpassed crop or varietal difference in susceptibility to toxicity as the factor controlling phytotoxicity. The observation of continued pH lowering, after an initial short-lived pH rise, and the observed pH dependence of toxic metal injury, suggested that control of the final equilibrium pH of deep incorporated sludge (as in trenches) is very important.

APPENDIX

Report on Cooperative Research on Trenching

for Period May 1, 1974 through

November 1, 1974

by John M. Walker*
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USDA-ARS-NER-AEQI
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Research Conducted Under Interagency

Agreement EPA-IAG-D4-0510

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The studies on sludge entrenched in 1972 were continued. Nitrogen, chlorides, metals, pH, and coliform and salmonella bacteria were measured in entrenched sludge and in soils surrounding the trenches (Tables 1A-7A). Samples for these analyses were obtained from cross-sections dug in June 1974 across the digested sludge treatments (trenches 60 cm wide x 60 cm deep x 60 cm apart [60-60-60] and 60-120-120) and across the raw-limed sludge treatment (60-60-60).

Since the width of trench was not a variable, the two factors affecting the distribution of materials from sludge in soil around individual trenches were depth of trench (60 vs 120 cm) and kind of sludge (digested vs raw-limed).

Two years after entrenchment, digested sludge in the shallow trenches had been penetrated the deepest by plant roots. This caused dewatering, favored further decomposition, and apparently induced generally aerobic conditions. As a result most of the inorganic N was in the nitrate rather than the ammonium form (Tables 1A and 2A). This nitrate concentration around these trenches was generally higher at 2 years than it had been at 17 months. The deeper digested sludge trenches, even after 2 years, were only partially penetrated by roots and therefore, still anaerobic in the lower portion. Consequently, nitrification was inhibited and NH_4-N predominated over NO_3-N. The same was true for the shallow trenches of raw sludge. In this case root penetration appeared to be inhibited by toxicity factors associated with the raw-limed sludge. These toxicity factors have not been defined. Slower sludge decomposition is probably desirable from the standpoint of slow release of NO_3-N.

The pH of the entrenched sludge and the soil below (Table 3A) is related to the predominant form of N present (Table 1A and 2A), which in turn is partly related to the degree of sludge decomposition and aeration. The pH is higher when the NH_4-N form of N is present. It will be interesting to see how high the pH will remain when NO_3-N becomes the predominant form of N in and around high lime sludge.

Chloride movement out of the different entrenched sludges (Table 4A) was apparently not closely related to the degree of sludge decomposition. Chloride movement was somewhat greater under the raw-limed than digested entrenched sludges at both sampling dates. Chloride movement into soil below the trenches was less in all cases at 25 than at 17 months while NO_3- and NH_4-N movement had increased in most cases over the same period. period.

A small amount of Zn had moved down at least 45 cm from the most decomposed aerobic sludge (60-60-60 digested, Table 5A) 25 months after entrenchment. Zn had not yet moved, however, out of the less decomposed aerobic digested sludge in the 60-120-120 trenches. Zn also had not moved out of the 60-60-60 entrenched raw-limed sludge. This movement of Zn out of the 60-60-60 entrenched digested sludge is probably related to the low soil and sludge pH (Table 3A), which in turn is related to the degree of decomposition, the form of N, and the presence of lime. Additional experiments will have to be run to determine whether this increased movement of Zn is related solely to chemical changes associated with changes in pH or to other changes in chemical status due to decomposition. Cu had not moved out of any entrenched sludge (Table 6A). Cu is more strongly bound than Zn.

No fecal coliform or salmonella bacteria were detected in any of the sludges or in the soil below at either 17 or 25 months after entrenchment. Only total coliform bacteria were still surviving. In one instance these bacteria apparently moved 45 cm below the entrenched sludge (Table 7A).

In a cross-section previously dug across a 60-120-120 digested sludge trench (November 1973), sludge had mostly been converted into a moist peat-like structure without roots. This pit was dug on the upper side of the plot with the water table at approximately 4 to 5 m below the sewage sludge. In June 1974, a cross-section was dug across the same treatment area in a region where the water table was approximately 2 m below the soil surface. Much of this sludge was unchanged from its original sludge-like consistency, suggesting that closeness to water table may have a bearing on the speed of sludge decomposition. This possibility will have to be studied in the future for verification.

The 60-60-60 raw-limed sludge was still slowly being converted from a sludge-like to peat-like consistency. The peat-like zone extended from the top approximately 1/4 of the way down into the entrenched sludge. The part of the sludge converted to peat-like consistency contained roots. The water table was approximately 1.5 m below the soil surface in this treatment. Perhaps this high water table was partly responsible for the slow dewatering. We have had no raw-limed sludge treatment in areas where the water table was deeper.

Subsurface and drainage water has been monitored since the beginning of this study (Table 8A). These water samples are taken from: (a) sample wells throughout the site, (b) drain lines around the site, and (c) a catchment pond receiving drain line flow and surface runoff.

Analyses of well waters have not as yet shown increased levels of NO_3- or NH_4-N; but increased levels of chloride compared with before sludge application were still observed 25 months after entrenchment. In tile drainage water, NO_3-N in particular has steadily increased while chloride has increased and then decreased. Levels of NO_3- and NH_4-N in the pond water are considerably below the levels in drainage water and have not as yet reached hazardous levels. Chloride levels in the pond have remained low and have not undergone appreciable change. There is some possibility that surface and perhaps even subsurface water with low levels of NO_3- and NH_4-N and chloride have entered the pond and caused some dilution. Whether there has been loss or dilution of these materials by some other mechanism is not known. Analyses of sludge, soil, and water samples continues to indicate that movement of NO_3-N may be an important problem at soil entrenchment sites.

Samples of fescue and alfalfa plants were taken that were growing over the sample trenches (Table 9A), and between and directly over other trenches (Table 10A). Uptake of Zn by fescue was approximately 4 times greater in plants grown over digested than raw sludge. Uptake of Cu and B was approximately 2 times greater over the digested than the raw shallow trench treatments. This lower uptake over raw sludge reflects both its lower initial trace element concentration and its higher lime and pH level. Highest metal uptake by fescue occurred in plants growing directly over trenches (Table 10A), while alfalfa plants absorbed metals independently of their location with respect to the entrenched sludge. These results indicate the greater spread of alfalfa roots in the soil.

Table 1A. NITRATE-NITROGEN MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location		NO_3-N (μg/g dry wt) in and around sludge in trenches with time (months)					
		60-60-60				60-120-120	
		Raw limed		Digested		Digested	
		17	25	17	25	17	25
Above sludge		13	10	5	1	-	2
Entrenched sludge	i*	1,900	496	1,200	1,076	600	9
	ii**	110	586	40	1,654	40	35
Cm below sludge	2.5	243	4	25	39	3	2
	15	45	4	21	13	3	2
	30	7	3	12	12	3	8
	45	7	3	15	7	5	8
	60	6	4	8	4	2	4

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 2A. AMMONIUM-NITROGEN MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location		NH_4-N (μg/g dry wt) in and around sludge in trenches with time (months)					
		60-60-60				60-120-120	
		Raw limed		Digested		Digested	
		17	25	17	25	17	25
Above sludge		1	4	7	1	-	1
Entrenched	i*	28	78	439	14	362	14
sludge	ii**	2,523	7,411	4,392	206	2,990	3,992
Cm below	2.5	232	420	104	10	152	134
sludge	15	91	373	90	6	134	124
	30	31	96	64	4	51	60
	45	9	95	57	2	28	44
	60	1	38	28	2	7	42

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge

Table 3A. THE pH OF ENTRENCHED SLUDGE AND SURROUNDING SOIL

Location		The pH in and around sludge in trenches with time (months)					
		60-60-60				60-120-120	
		Raw limed		Digested		Digested	
		17	25	17	25	17	25
Above sludge		4.3	5.7	4.9	5.2	-	4.5
Entrenched sludge	i*	4.1	6.7	6.9	5.1	5.1	5.0
	ii**	7.4	7.3	6.9	5.5	7.8	8.0
Cm below sludge	25	6.5	8.3	4.7	4.5	7.4	8.0
	15	5.4	8.3	7.3	4.7	4.8	7.9
	30	4.5	8.0	7.2	4.6	4.6	7.5
	45	4.8	7.8	7.3	4.7	4.4	6.9
	60	4.7	7.4	7.2	4.7	4.5	6.5

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 4A. CHLORIDE MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location		Chloride (μg/g dry wt) in and around sludge in trenches with time (months)					
		60-60-60				60-120-120	
		Raw limed		Digested		Digested	
		17	25	17	25	17	25
Above sludge		18	29	-	22	-	8
Entrenched sludge	i*	23	1,196	123	50	33	31
	ii**	4,900	5,360	5,300	1,332	4,150	4,025
Cm below sludge	2.5	102	55	97	40	69	49
	15	51	59	48	27	68	49
	30	29	40	30	24	33	42
	45	36	32	46	23	52	34
	60	10	36	30	22	41	31

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 5A. TOTAL AND DTPA EXTRACTABLE ZINC MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location		Zinc (μg/g dry wt) in and around sludge in trenches with time (months)								
		60-60-60						60-120-120		
		Raw limed			Digested			Digested		
		17	25		17	25		17	25	
		DTPA	DTPA	Total	DTPA	DTPA	Total	DTPA	DTPA	Total
Above sludge		0.4	1.1	15	0.4	0.3	13	1.3	0.5	13
Entrenched sludge	i*	313	328	769	1,060	647	1,249	-	1,197	1,300
	ii**	215	367	660	490	548	1,228	582	665	1,044
Cm below sludge	2.5	0.5	0.1	6	0.8	8.8	32	0.3	0.1	3
	15	0.1	0.2	-	0.2	2.6	12	0.2	0.1	2
	30	0.2	0.2	-	0.1	0.9	7	0.2	<0.1	2
	45	-	0.4	-	0.0	0.7	4	-	0.1	1
	60	0.1	0.1	3	0.2	0.3	3	0.2	<0.1	-

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 6A. DTPA EXTRACTABLE AND TOTAL COPPER MOVEMENT INTO SOD FROM ENTRENCHED SLUDGE

Location		Copper (μg/g dry wt) in and around sludge in trenches with time (months)								
		60-60-60						60-120-120		
		Raw limed			Digested			Digested		
		17	25		17	25		17	25	
		DTPA	DTPA	Total	DTPA	DTPA	Total	DTPA	DTPA	Total
Above sludge		0.4	0.6	-	0.5	0.2	4	0.7	0.4	4
Entrenched	i*	113	208	425	365	289	544	-	322	928
sludge	ii**	58	129	378	22	160	466	74	80	359
Cm below	2.5	0.5	0.3	3	0.4	0.2	5	0.5	0.2	3
sludge	15	0.3	0.4	-	0.4	0.1	3	0.4	0.1	2
	30	0.3	0.3	-	0.3	0.1	3	0.3	0.1	2
	45	-	0.2	-	-	0.1	2	-	0.2	1
	60	0.3	0.2	2	0.1	0.1	2	0.6	0.2	-

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 7A. TOTAL COLIFORM MOVEMENT INTO SOIL FROM ENTRENCHED SLUDGE

Location		Total coliform (MPN/g dry wt) in and around sludge in trenches with time (months)					
		60-60-60				60-120-120	
		Raw limed		Digested		Digested	
		17	25	17	25	17	25
Entrenched sludge	i*	180,000	150,000	32,000	<5	27,000	62,000
	ii**	590	3,000	68	23,000	<7	<9
Cm below sludge	2.5	10	970	<3	<3	3	<3
	15	<3	380	<3	<3	<3	<3
	30	<3	1,100	<3	<3	<3	<3
	45	<3	1,100	<3	<3	<3	<3
	60	<3	<3	<3	<3	<3	<3

* More weathered, aerobic sludge.

** Less weathered, less aerobic sludge.

Table 8A. CONTENTS OF NH_4-N, NO_3-N, AND Cl IN UNDERGROUND, DRAINAGE, AND STORED WATER FROM TRENCH AREA

Date	mg/l in water: Well 16 *			Drain 71 **			Pond		
	NH_4-N	NO_3-N	Cl	NH_4-N	NO_3-N	Cl	NH_4-N	NO_3-N	Cl
Before sludge (Apr. 72)	<1	<1	2	<1	<1	10	-	-	-
Oct. 73	<1	1	90	7	5	32	<1	5	33
Nov. 73	<1	1	64	15	7	80	<1	5	44
Jan. 74	<1	1	49	4	12	106	<1	3	20
Mar. 74	<1	1	64	4	21	117	<1	6	43
Apr. 74	<1	1	46	12	21	90	1	7	35
July 74	<1	1	48	9	14	36	1	8	39
Aug. 74	<1	<1	39	-	-	-	-	-	-
Nov. 74	<1	<1	42	6	30	33	1	7	31

* A representative well located in area B in 60-60-60 digested sludge trench plot.

** Drains plot area A in sandy soil.

Table 9A. ELEMENTAL CONTENT OF FESCUE HARVESTED OVER THE 60-60-60 ENTRENCHED SLUDGE* AFTER 25 MONTHS

Sludge type	Element				
	Major, %				
	N	P	K	Ca	Mg
Digested	2.5	0.23	1.41	0.75	0.29
Raw	2.5	0.30	2.18	0.53	0.29
	Minor, μg/g dry wt				
	Zn	Cu	Mn	Fe	B
Digested	120	12	264	86	9
Raw	28	6	195	79	5

* There was approximately a 25 cm layer of soil without sludge covering the entrenched sludge.

Table 10A. ELEMENTAL CONTENT OF FESCUE AND ALFALFA GROWING OVER AND BETWEEN 60-60-60 DIGESTED SLUDGE* TRENCHES AFTER 25 MONTHS

Plant and location	Element				
	Major, %				
	N	P	K	Ca	Mg
Fescue					
between trenches	2.3	0.34	2.80	0.49	0.29
over trenches	3.7	0.40	2.55	0.66	0.66
Alfalfa					
between	4.4	0.40	2.21	1.16	0.34
over	4.6	0.39	2.13	1.30	0.33
	Minor, μg/g dry wt				
	Zn	Cu	Mn	Fe	B
Fescue					
between	71	5	219	53	3
over	173	7	279	58	4
Alfalfa					
between	162	9	113	87	22
over	173	9	139	69	23

* There was approximately a 25 cm layer of soil without sludge covering the entrenched sludge.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-75-034		

4. TITLE AND SUBTITLE
TRENCH INCORPORATION OF SEWAGE SLUDGE IN MARGINAL AGRICULTURAL LAND

5. REPORT DATE
September 1975 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Dept. of Agriculture, Biological Waste Management Laboratory,ARS, Beltsville,MD; for Maryland Environmental Services, Annapolis,MD; and Government of the District of Columbia, Dept. of Env. Services, Washington, D.C.

10. PROGRAM ELEMENT NO.
1BB043 (ROAP 21-ASE, Task 027)

11. CONTRACT/~~GRANT~~ NO.
68-01-0162

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final, 10/71 to 1/74

14. SPONSORING AGENCY CODE
EPA-ORD

15. SUPPLEMENTARY NOTES
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Biological Waste Management Laboratory
Agriculture Research Service, Beltsville, Maryland

16. ABSTRACT

A trench method was tested for transporting and placing digested and limed raw (undigested) sewage sludges (8% and 20% solids) in trenches in study soil at loadings up to 1150 dry tons/hectare (500 dry tons/acre) without odor problems or hazard of surface runoff. Field scale trenching was best achieved by digging the trenches on contour not more than 75 cm deep, 60 cm wide, and from 60 to 75 cm apart. The study indicated that the best sludge transport method would employ concrete mixer trucks. Trenches could then be filled directly from discharge chutes or indirectly with a peristaltic pump. A tracked trenching machine with a maneuverable rear-mounted digging wheel dug a new trench and simultaneously backfilled a parallel sludged trench. In 2 years, neither heavy metals nor pollution indicator organisms (coliform and salmonella) have moved more than about 30 cm from entrenched sludge into surrounding soil. Moderate amounts of nitrate nitrogen have moved into underdrainage water but not into the underground aquifier. The lime in the sludge reduced metal movement into soil and availability to crops and metal uptake was modest. Tested agricultural practices included cross ripping, tilling, and cropping, with grasses recommended for the first year. Entrenchment appeared feasible for sludge disposal and improving marginal land.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge disposal*	Limed raw sludge*	13B
Land reclamation*	Digested sludge*	
Trenching*	Lime	
Salmonella	Metals	
Coliform bacteria	U.S. Agricultural Research Service, Beltsville, Maryland	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	250
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)